AIR FORCE MANUAL

ICE AIRFIELDS

10 SEPTEMBER 1958

ARTMENT OF THE AIR FORCE

AIR FORCE MANUAL
No. 86–5

DEPARTMENT OF THE AIR FORCE
WASHINGTON, *10 September 1958*

Foreword

1. *Purpose.* This manual is designed to provide USAF personnel with scientific facts concerning the landing of aircraft on floating ice surfaces. The bearing strength of ice is a complex technical subject. This manual is designed to provide a handbook that will reduce technical terms of ice physics to language the layman can readily understand.

2. *Scope.* This manual contains a brief history of aircraft landings on ice to illustrate the development of operational techniques. The techniques presented have been proven by field application but they are subject to revision as more is learned about the bearing strength of floating ice surfaces. The manual also contains basic information to guide USAF personnel in planning the selection, establishment and use of ice airfields.

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HISTORY OF AIR OPERATIONS ON FLOATING ICE

1. The DEW Line Airlift

In February 1955, an advanced target date for establishing the Distant Early Warning (DEW) line in northern Alaska and Canada presented the U. S. Department of Defense with an apparently unsolvable problem. Sea approaches to the proposed arctic radar sites would not be ice-free until late summer. Overland transport by tractor train could supply only a few of the sites; yet, construction had to begin immediately if the line were to be operational by the target date.

a. *Ice Landing Strips First Used.* Airlift seemed the only possible solution but no airstrips had yet been built at the sites, and the few ski-equipped aircraft available were too small to carry in the heavy equipment needed to construct conventional airfields. The only available carriers capable of transporting the necessary equipment and supplies in time to meet the construction schedule were C–124's. These aircraft, not being ski-equipped, apparently could not land the tractors, graders, and other strip-building equipment until the strips for C–124's somehow had been built—yet loaded C–124 aircraft began landing near the sites early in March. From 10 March to 20 May 1955, C–124's of the 18th Air Force (TAC) flew 932 sorties to DEW line sites and airlifted 18,000 tons of cargo. The quandary posed by the apparent lack of airfields was by-passed by using the natural ice cover of the sea and of fresh water lakes for landing strips. Twenty-eight ice runways were used—18 on sea ice and 10 on fresh ice.

b. *DEW Line Contributes to Criteria for Ice Airfields.* Although the C–124's weighing 168,000 pounds were by far the heaviest aircraft ever to land on floating ice, the decision to use ice runways was not a desperate, last-chance gamble, but was based on reliable engineering data gathered from field tests and actual operations. Ice scientists gathered additional data during the DEW line airlifts of 1955 and 1956, and their work has done much to standardize the procedures and measurements necessary for the selection of safe ice airfields.

2. First Uses of Ice Airfields

In northern Europe, Alaska, and Canada, light aircraft have been using frozen rivers and lakes and landfast sea ice as winter landing fields ever since airplanes began flying in these areas. Aircraft have operated off floating sea ice in explorations of the Arctic since 1923, when Roald Amundsen carried a Curtiss biplane on skis on the "Maud," and in the Antarctic since 1928 when Sir Hubert Wilkins and Lt. Carl Ben Eielson flew to the Palmer Peninsula from Deception Island. Both the bush pilots and the explorers used relatively light aircraft, usually single engine.

a. *Russian Experience.* The Russians made the first ice landings with heavy multiengine aircraft in 1937 during the first Soviet North Pole Expedition. During this expedition the Russians made 13 landings on unprepared ice floes. The ANT–6 weighing approximately 50,000 pounds was the heaviest aircraft they used.

(1) *Wheeled Aircraft Operated on Smooth Ice.* Prior to this time, most aircraft operating off ice had been equipped with skis or with pontoons that functioned

as skis. During their 1937 operations, the Russians found that wheeled aircraft could land and take off from smooth ice, except where thick snow cover interfered with the wheels.

(2) *Soviet Data Used by USAAF in WW II.* A paper written in 1938 by a Russian, K. A. Moskatov, was the primary source of information on ice strengths and operating criteria for the U. S. Army Air Forces during World War II. Soviet arctic research was intensified during World War II and, with the end of hostilities, was pursued with even greater vigor.

(3) *Soviet Air Operations on Polar Pack Become Routine.* By 1957 the Russians had established, and supplied by air, six major stations on the polar pack and had manned each for periods of up to a year. Each station required selection of ice landing strips for air delivery of men and materiel. In addition, the Russians have used aircraft extensively in their high-latitude scientific research program and have made many ice landings at the complex of satellite stations around the major stations. The scope of Soviet air operations on the polar pack suggests that they consider as routine the air operations on and off floating ice. The Russians make extensive use of landfast sea ice and frozen rivers and lakes as airfields during the winter. In northern Siberia, the ice airfields are operational much of the year.

b. *United States Experience.* The United States has not carried out arctic operations on the same scale as the Soviet Union has, but both the U. S. Air Force and the U. S. Navy have had considerable experience with ice airfields.

(1) *C–54's and C–47's Land on Fast Ice in Canadian Arctic.* During World War II a variety of aircraft, the heaviest being a C–54, used the fast ice as an airfield at Crystal III (Padloping Island) on the northeast coast of Baffin Island and made more than 100 landings there. C–47's and C–54's also landed on fast ice at other installations in the Canadian arctic on routine supply operations and on mercy flights.

(2) *Ice Strips Used in Exercise Muskox.* During the Canadian–U. S. Exercise *Muskox* in March 1946, C–47's, Norsemen, and gliders operated from ice landing strips at Cambridge Bay and Coopermine. In establishing the Canadian–U. S. weather stations at Alert, Eureka, Mould Bay, and Isachsen, C–54's and lighter aircraft used landfast sea ice and fresh water ice as landing strips. Similar ice strips have been used on the yearly resupply missions each spring since 1947.

(3) *Loran Equipment Landed on Ice Strips in Project Beetle.* The first of the large airlifts to use ice landing strips was the *Beetle* Project of 1947, during which 1,100 tons of supplies and equipment for loran stations were flown to remote arctic locations from Canadian air bases. The landing strips at these stations were on smooth, landfast sea ice. Most of the landings were by C–54 aircraft grossing about 68,000 pounds—a few by lighter C–82 aircraft. Completion of the project required that equipment too large to be carried in a C–54 or C–82 be delivered to Cambridge Bay, Victoria Island, N. W. T.

(a) An aircraft larger than a C–54 had never landed on ice, and the thickness necessary to support a heavier aircraft never had been determined. Even though many C–54's had landed on ice, not enough data on ice strengths were available to compute *accurately* the minimum thickness required for aircraft heavier than 45,000–50,000 pounds' landing weight.

(b) Major General William H. Tunner, then Commander of the Atlantic Division, Air Transport Command, decided to attempt a landing at Cambridge Bay with a C–74 aircraft. According to the data on ice strengths in use at that time, a C–74 at 130,000 pounds landing weight would have needed at least 74 inches of sea ice to support it; some estimates ranged upward to 123 inches, depending on the data and criteria used. There were 86 inches of ice at Cambridge Bay. Though some doubt was expressed that the 86 inches would hold the C–74, it landed at a gross weight of 129,500 pounds without any noticeable effect on the ice.

(4) *Rescue Squadron Establishes Camp North of Barter Island.* From 1949 through the spring of 1951, the 10th Rescue Squadron made more than 150 landings on pack ice off the Alaskan coast with ski-wheel C–47's. On 20 February 1951, the 10th Rescue Squadron established a camp by a frozen lead in the pack ice approximately 100 miles north of Barter Island. After the ice broke up during a strong gale, they abandoned the camp and evacuated all personnel by air on 12 March 1951.

(5) *Landings on Ice in Operations Skijump I and II.* During Operations *Skijump* I and *Skijump* II (1951-1952), the U. S. Navy made more than 20 landings with P2V's and C–47's on the pack ice north of Alaska.

(6) *Wheel Landings Now Possible at Camp on T–3 Island.* On 19 March 1952, an Alaskan Air Command C–47 on skis landed on the ice island T–3 to establish a camp that was manned continuously until 1954 and intermittently ever since. C–47's, P2V's, C–54's, and C–124's have made wheel landings on T–3 since the initial ski landing.

Most of the U. S. operations described above gathered data on ice characteristics, especially ice thicknesses, for analysis by cryologists (ice scientists). In 1946 the Arctic Construction and Frost Effects Laboratory, Corps of Engineers, U. S. Army, in cooperation with the Air Transport Command, conducted studies and experiments on the problems involved in establishing and maintaining an airfield on ice. Later the Snow, Ice, and Permafrost Research Establishment (SIPRE), Corps of Engineers, continued this work and developed the test methods and criteria used so successfully on the DEW line in 1955. As a result of this close cooperation between the operating agencies and the research agencies, the scientists have been able to check their computations against actual experience and thus develop more realistic criteria. Prior to 1954, the best available engineering estimates indicated that sea ice for fully loaded C–124 operations should be at least 97 inches thick. In 1955 this estimate was reduced to 67 inches. In 1956 it was further reduced to 54 inches, and as yet no aircraft has been lost through ice failure.

3. Kinds of Ice Used for Aircraft Operations

Before discussing the criteria for selecting ice landing fields, it is necessary to define the terms used in this manual to describe natural ice surfaces. The conventional classification, used by most hydrographers and cryologists, divides natural ice into four main classes—*sea, lake, river,* and *land ice*—all of which have been used as airfields. From the standpoint of airfield selection, we can rearrange this classification as shown below.

a. *Ice on Water*
- (1) *Sea ice.*
  - (a) Fast ice.
  - (b) Pack ice.
    - *1.* Floes.
    - *2.* Frozen leads.
- (2) *Ice islands* *.
- (3) *Lake ice.*
- (4) *River ice*

b. *Ice on Land*
- (1) *Firn.*
- (2) *Glaciers.*
- (3) *Ice caps.*
- (4) *Ice shelves* *.

4. Ice on Water

Of the two main categories listed above, ice on water has been used far more extensively for military operations.

a. *Sea Ice.* Sea ice is formed by the freezing of salt water, whether the ice is floating freely in the sea or is attached to the shore.

(1) *Fast Ice.* Any type of sea ice—either broken or unbroken—which is attached to the shore, beached, or stranded in shoal water is called *fast ice* by hydrographers. Usually, only unbroken fast ice attached to a shore or filling a bay or lagoon is used

* Ice islands and ice shelves are the same kind of ice. The ice island is floating freely in the sea; the ice shelf is attached to land ice on the shore and is only partially supported by water.

for landing strips. Most of the ice landing strips used on the DEW line were on fast ice. The landing strips used on Operation *Deep Freeze* in the antarctic in 1956 and 1957 were also on fast ice.

Figure 1. Photograph of landing strip on fast ice.

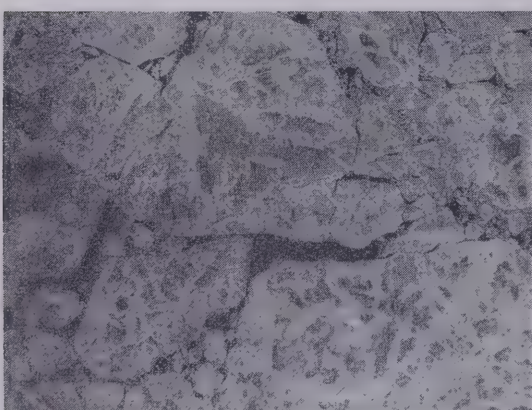

Figure 2. Arctic pack in July.

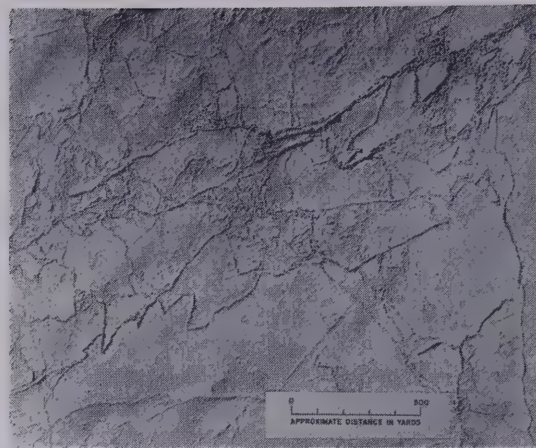

Figure 3. Arctic pack in January.

(2) *Pack Ice.* Any large area of floating ice driven closely together is called *pack ice.* Figure 2 is an aerial photograph of pack ice, part of the *Arctic Pack,* taken in July.

(3) *Floes.* The individual fragments of ice are *floes.*

(4) *Leads.* The lanes of water between the floes are *leads.*

Figure 3 is an aerial photograph of the same type of ice in January. Note that the individual floes and the leads, although frozen, are still identifiable. Aircraft have landed and taken off from floes since 1923 when Amundsen made his pioneering flights. Most floes within the Arctic Pack are thick enough to support any aircraft. The factor limiting their use is their irregular surface. Minor hummocks and pressure ridges can be smoothed out by cutting and filling, but the larger pressure ridges (see Figures 2 and 3) are usually immovable barriers. The factor limiting construction of airstrips on ice floes is not the size of the individual floes, which may be miles across, but the distance between pressure ridges. In the opinion of many experienced pilots, the smooth ice of frozen leads offers the best surface for landing

Figure 4. Photograph of aircraft on ice strip on floe.

Figure 5. C–47 on wheels on frozen lead.

strips in pack ice. USAF and US Navy aircraft have operated from frozen leads, just as the Russian aircraft have. Because leads form and refreeze even in midwinter, the thickness and, therefore, the strength of the ice in frozen leads vary greatly in the same area. Careful low-level reconnaissance is necessary before landing.

b. *Ice Islands.* Ice islands are large, tabular masses of ice, in the Arctic Ocean or adjacent waters, more than a hundred feet thick and several square miles in area. Ice islands usually have a gently undulating surface of alternating ridges and depressions. They are not sea ice but appear to be fragments broken from very thick shelf ice, such as the Ellesmere Ice Shelf.

(1) *Locations of Ice Islands Found by Aerial Reconnaissance.* Sixty ice islands with a total area of approximately 1,000 square miles have been located by aerial reconnaissance and study of aerial photographs. Fifteen are in the Arctic Ocean, the remainder in channels of the Canadian Arctic Archipelago. Ice island T–3, also called "Fletcher's Island," has been occupied intermittently by the USAF since the first landing on it in March 1952. Several aircraft have made wheel landings on T–3, including a C–124. The larger ice islands (T–1, T–2, T–3, and others not identified by name or number) are more permanent than the floes of the pack. Their drift through the Arctic Ocean can be plotted with some accuracy. Their relatively smooth surfaces allow landings of the largest aircraft and, more important, airstrips sited on ridges are thought to be usable the year around.

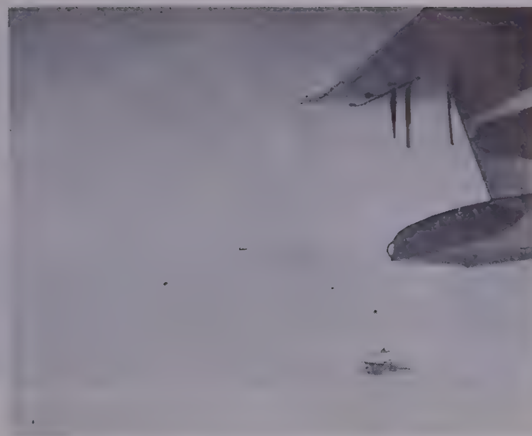

Figure 6. Aerial photograph of ice island T–3 showing aircraft on the surface.

Figure 7. Aerial photograph of ice island T–1.

c. *Lake Ice.* Lake ice is fresh water ice formed in lakes. Lake ice is often used for airstrips. Several of the DEW line ice landing strips were on lakes. Lakes generally freeze with a smooth surface, but intermittent thaws or wet snowfall will roughen the surface. Small lakes freeze sooner than large ones, and shallow lakes may freeze solid. Lake ice usually is relatively thin and weak in the vicinity of outlets or inlets of streams.

d. *River Ice.* River ice is any ice formed in or carried by rivers. Usually, only un-

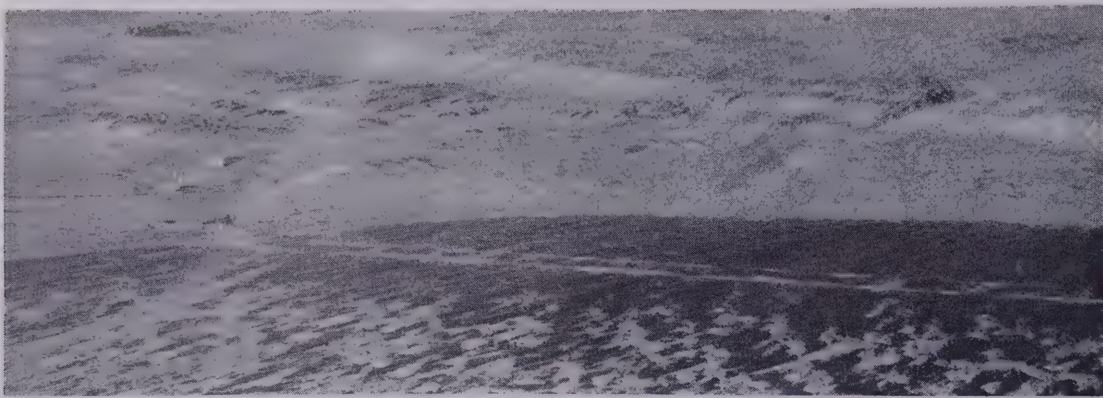

Figure 8. Photograph of landing strip on Hall Lake.

broken river ice that has not moved from its place of formation is used for airstrips. River ice has been used as a landing surface, especially for small aircraft, since World War I. The ice that forms on broad, slow-moving rivers frequently has the same smooth surface as lake ice. If, however, an early ice surface is broken by warm weather and wind and then refrozen, a rough surface forms that will remain throughout the winter. This roughening of the surface may occur from year to year in the same sections of some rivers. The ice on fast-flowing rivers is usually poor, because rapidly flowing water seldom freezes into thick, sound ice.

5. Ice on Land

Land ice is any ice formed on land, whether found on land or floating in the sea as icebergs or ice islands. Land ice is formed by the transformation of accumulated snow into ice. This transformation usually takes many years.

a. *Firn.* This is old snow that has lasted through at least one summer; the flakes have changed to grains of spherical shape, which may or may not be bonded together. Firn may later become glacial ice. Firn is denser than snow but not as dense as ice, and normally will not support the high-tire footprint pressures of USAF aircraft. Firn occurs on the upper areas of glaciers, on higher elevations of ice caps, and in the upper layers of some ice shelves.

b. *Glaciers.* A glacier is a mass of snow, firn, and ice which is flowing or has flowed. Glaciers are usually confined in mountain valleys. In some areas, light ski planes have used glaciers for landing strips. Larger aircraft on skis and amphibian aircraft on skids have landed and taken off from the firn fields at the heads of glaciers. Glaciers usually are poor landing fields because their movement often causes large cracks, known as crevasses, to form. Unless the location

Figure 9. Aerial photograph of valley glacier showing firn field of collecting basin and crevasses in body of glacier.

Figure 10. Photograph of SA–16 landing on Juneau ice field or other firn-covered area in Alaska.

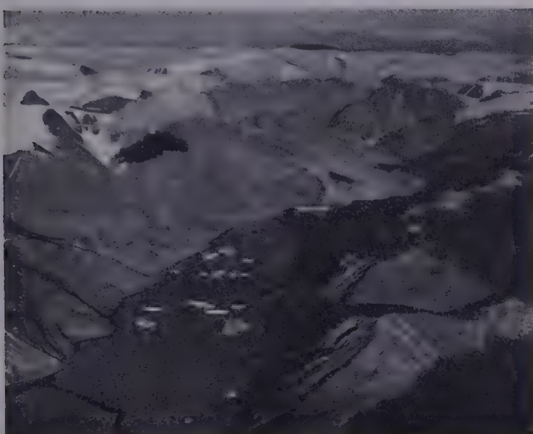

Figure 11. Photograph of Greenland Ice Cap Glacier.

of each crevasse is known, landing on a glacier is dangerous.

c. *Ice Caps.* An ice cap is a sheet of land ice covering a large portion of a land area. The best known is the Greenland Ice Cap, which covers all but the mountainous rim of Greenland. Ice caps have been used routinely by ski-equipped aircraft but most ice cap surfaces, being snow or firn, are unsuitable for wheel landings.

(1) *Greenland Ice Cap.* Ice landing strips for wheeled aircraft can be prepared on the Greenland Ice Cap, but are restricted to the basal ice with thin snow cover or refrozen lakes and slush fields. These conditions are found at some localities in a belt about 10 miles wide in the margin of the interior plateau. This belt extends just above and below the firn limit (the lowest portion of the permanent snow cover of the ice cap) but will vary in position from year to year depending on climatic fluctuations. Although designated as an ice cap *, the major portion of the Greenland Cap is covered by permanent layers of snow from a few inches to approximately 200 feet thick. As the snow accumulates, the effects of weather plus the pressure of overlying layers change the snow first into firn and then into ice. At lower elevations of the ice cap, approximately between 5,000 and 6,000 feet, the snow and firn layers become thinner until gradually the basal ice is very close to the surface and is covered only by the annual winter snow, which melts away exposing the basal ice.**

Figure 12. Aerial photograph of *Mint Julep* strip.

d. *Ice Shelves.* An ice shelf is a thick ice formation, with a comparatively level surface, attached to land and extending sea-

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* Some glaciologists prefer to call glaciers covering very large areas (e. g. Greenland and Antarctica) continental glaciers or ice sheets. The smaller glaciers covering smaller areas are called glacier caps or ice caps (e. g. Vatnajokul in Iceland and other large glaciers in Norway and Canada).

** A report of an investigation of smooth ice areas of the Greenland Ice Cap (Project *Mint Julep, Adtic, Rsi,* Air University) describes in detail the phenomenon of basal ice and its use for airstrips.

Figure 13. Aerial photograph of Greenland Ice Cap looking inland from Sondre Stromfjord.

ward. Ice shelves are formed by the accumulation of snow on landfast ice, with a subsequent transformation to firn and ice, or by the seaward extension of glaciers. Landing strips for aircraft on skis have been prepared on antarctic ice shelves by several expeditions. Because the upper layers of these ice shelves consist of firn, not ice, wheel landings are impossible without extensive construction and processing. On some arctic ice shelves, the Ellesmere Island Ice Shelf, for example, the basal ice is at or so close to the surface that airstrips for wheeled aircraft can be constructed quite easily. The ice island T–3, on which a C–124 has landed successfully, is thought to be a floating fragment of the Ellesmere Ice Shelf.

Figure 14. Photograph of C–47 landing on Greenland Ice Cap.

Figure 15. Aerial photograph of Ellesmere Ice Shelf.

Chapter 2

ENGINEERING CONSIDERATIONS

6. Ice As an Engineering Material

The use of ice as a material in any type of construction presents many problems because, under sudden high stress, ice may fracture like glass. Steady or gradually increasing stress may cause it to flow and deform like a viscous liquid. The bearing strength of an ice sheet varies with its structure, its salinity, purity, and temperature, and with its underlying medium—air, water, or unfrozen ground. The same piece of ice will change strength when exposed to changing environmental temperatures. Inclusion of foreign matter, inevitable in natural ice, also affects its strength. Floating ice varies in strength throughout the sheet, because it is exposed to one environmental temperature at the top and another at the bottom.

a. *Advantages of Ice as Material for Landing Strips.* The advantages of using natural ice as a material for landing strips are obvious. It is available, and no construction is necessary other than removal of snow. Ice is not as strong as concrete, but it can be strong enough, depending on its thickness, to support any aircraft the Air Force uses or is likely to use. Many disadvantages, as this manual explains, can be overcome by intelligent planning.

b. *Snow Compacted Into Ice.* Snow cannot be compacted into ice to form a bearing surface that will support aircraft footprint pressures above 100 pounds per square inch, without using special equipment. Footprint pressures of USAF aircraft range from 50 pounds to 200 pounds per square inch. This manual will not discuss snow compaction, except in connection with the surfacing of ice runways and taxistrips.

7. Load-Bearing Capacity of Floating Ice Sheets

A floating ice sheet's capacity to bear a particular load depends on the sheet's resistance to bending. The parameters used by engineers to compute the curvature of bending of the ice surface include:

a. *Modulus of Elasticity.* Young's modulus of elasticity (the force in pounds per square inch divided by the relative deformation in the direction in which the force is applied),

b. *Ratios of Deformation.* Poisson's ratio (the ratio of the deformation perpendicular to the applied force and the deformation in the direction of the applied force),

c. *Water Pressure.* The pressure of the water against the ice cover when the ice bends,

d. *Physical Characteristics of Load.* The concentration and configuration of the load.

In practice the load-bearing capacity of a floating ice sheet can be expressed as a function of ice thickness, air temperature, water depth, and type of ice. The Snow, Ice, and Permafrost Research Establishment (SIPRE) has analyzed these factors as they affect landing of USAF aircraft. A load on the ice causes a saucer-shaped depression with a slightly raised rim. The distance to this rim, from the point at which the load is applied, is called the *influence radius.* Theoretical analysis, verified by observations in the field, shows that the influence radius

depends almost entirely on the thickness of the ice, *not* on the magnitude of the load. The influence radius may be smaller for static loads, such as parked aircraft, than for moving loads, such as taxiing aircraft. See the table in appendix 4 for safe parking intervals for specific aircraft. This table shows the thicknesses, at the various temperatures, of ice needed to land specific aircraft. *This table must not be used until the remarks accompanying it have been read and thoroughly understood.* Table 1, in this chapter, lists influence radii for slowly moving loads; this table should be used in determining airfield layout.

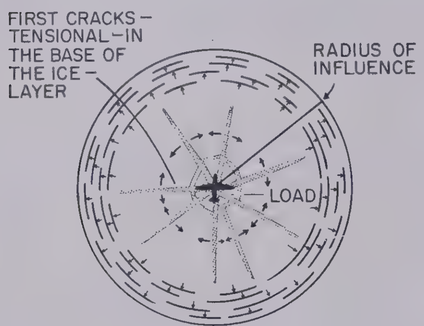


Figure 16. Diagram of ice sheet depressed under load, showing influence radius.

Table 1. INFLUENCE RADIUS OF SLOWLY MOVING LOADS ON FLOATING ICE

Ice Thickness (in Inches)	*Fresh Water Ice (in Feet)*	*Sea Ice (in Feet)*
10	90	80
15	120	110
20	150	140
25	180	160
30	200	180
35	230	210
40	250	230
45	270	250
50	300	270
60	340	310
70	380	350
80	420	380
90	460	410
100	500	450

e. *Resonance Waves.* Oscillations in the ice sheet, known as resonance waves, are caused by loads moving over the ice sheet. Resonance waves therefrom may cause deflections more than twice as great as deflections resulting from the same loads when stationary. The speed at which a moving load generates the maximum deflection is called the critical speed. Critical speeds vary with water depth, ice-sheet thickness, and the elastic properties of the ice (see graph 3 appendix 3).

(1) *Effect of Resonance Waves.* Resonance waves subject ice sheets to alternate compression and tension, sometimes severe enough to cause ice failure. Ice failure is most likely to occur when two waves supplement each other, as when a taxiing aircraft overtakes its own wave or the reflection of the wave from a shoreline.

(2) *Ways to Minimize Effects of Resonance Waves.* The effects of resonance waves may be reduced somewhat by landing the aircraft away from shore and by taking off with as light a load as possible. When two landing strips, preferably, are used—each be should aligned more than 45 degrees to the shore and should be separated by at least three times the influence radius of the ice (see table 1). SIPRE criteria, for the ice thickness necessary under regular operations (appendix 4), are computed with allowance of an adequate safety factor against resonance waves. The choice of a favorable location for the runway will provide for additional safety and is especially desirable under emergency conditions.

f. *Cracks.* Field tests by SIPRE have proven that loads causing complete failure of the ice may be several times as great as those causing the first cracking; therefore, the first cracking * should be regarded as a warning to remove or reduce the load on the affected surface, and not as a cause for panic. If the load is removed, the cracks will usually heal overnight.

(1) *Tension Versus Tensile Strength of the Ice.* The first cracks start in the bottom

* Cracking caused by load, not cracking because of thermal expansion, tidal action etc.

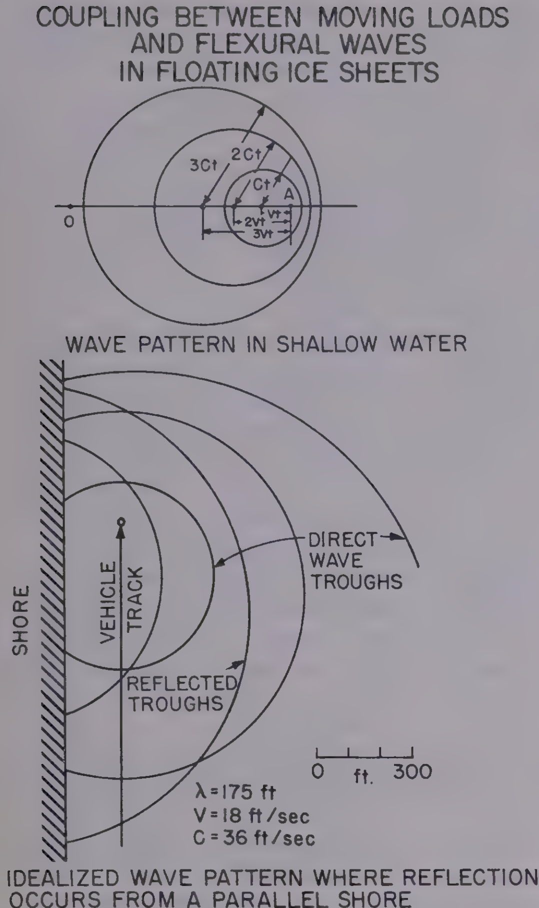


Figure 17. Diagram of a resonance wave.

surface where tension is greatest and are radial from the center. This first cracking is followed by a gradual slumping of the surface. A second major cracking occurs when the tension in the top surface exceeds the tensile strength of the ice. At this point, a circular crack develops suddenly several yards from the gear and the ice in the depressed area breaks into a number of pie-shaped pieces. After this second cracking, the ice will still support the load for a short time particularly if the ice is thick, but eventual breakthrough is unavoidable unless the load is removed.

(2) *Measurements of Deflection During Operations on Ice.* During all operations on ice of marginal thickness, measurements of

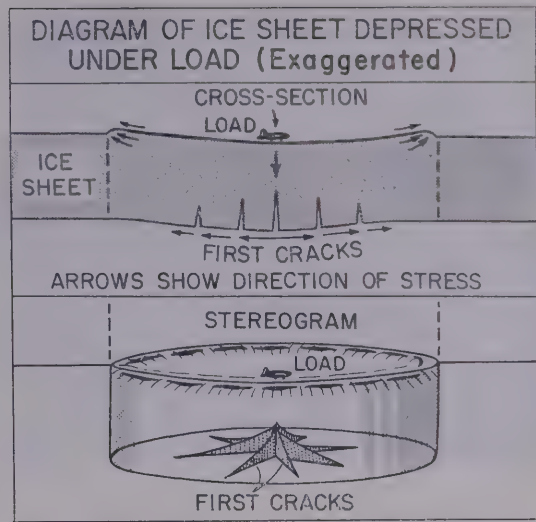


Figure 18. Drawing of ice cracking showing first cracks.

deflection under the load should be made continuously, as shown in figure 19, so that cracking may be anticipated and the loads moved in time. An increasing rate of deflection warns that the ice is failing and that the aircraft or other load should be moved before the surface cracks. A steady increase in deflection means "proceed with caution." There is no danger if the deflection does not increase. Figure 21 shows the deflections observed in C–124 operations at 154,000 pounds on ice 54 inches thick at 28°F. Note the rapidly increasing rate of deflection during the last few minutes. In this case, the

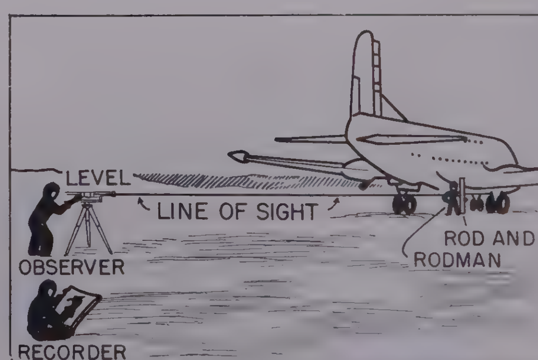


Figure 19. Diagram showing use of rod and engineer's level to measure deflection.

Figure 20. Photograph showing measurement of ice deflection with rod and engineer's level.

aircraft was moved immediately. Without the warning given by the deflection measurements, the aircraft might have broken through the ice.

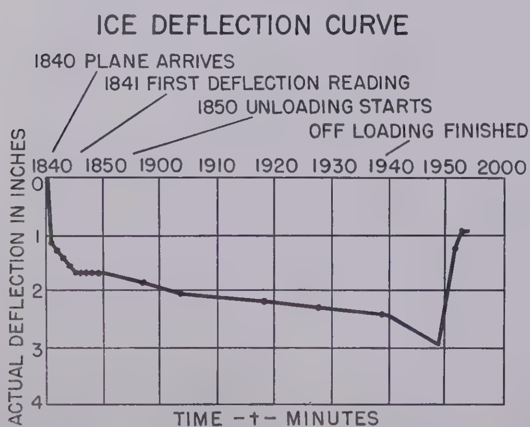


Figure 21. Deflections observed in C–124 operations.

8. Ice Growth and Distintegration

a. *Natural Growth.* A complete discussion of the thermodynamic and mechanical factors involved in the formation of an ice cover on a natural water surface is beyond the scope of this manual; however, the basic process, the transfer of heat from the liquid water to the air, should be understood.

(1) *Comparison of Cold and Heat.* Contrary to popular belief, "cold" does not "penetrate" materials exposed to a cold environment. "Cold" is merely the relative absence of heat. Heat is a form of energy. Heat will flow from a warm body exposed to a colder environment until the body and the environment are the same temperature. Similarly, heat will flow into a cold body exposed to a warmer environment. Insulation does not keep "cold" out, but merely retards the outward flow of heat.

(2) *Effects of Cold and Heat in Forming Ice.* As water changes from a liquid to a solid state, it releases heat. Ice begins to form on water when contact with cold air reduces the temperature of the surface layer below the freezing point. Heat released by the water as it solidifies supplies the difference between the amount of heat entering the ice from the water below and the amount of heat released by the ice to the air. The ice layer continues to grow thicker as long as more heat passes from the ice to the air above, than enters the ice from the water on which it floats. The ice stops growing when the amount of heat escaping from the ice to the air equals that entering the ice from the water. When the air warms enough (even though still at a subfreezing temperature) so that it is unable to carry away the heat of the underlying water, the ice begins to melt from below and to diminish in thickness and strength. This will continue until the heat flowing *in* is balanced by the heat flowing *out*. When the air temperature rises above freezing, the heat entering the ice both from above and below accelerates disintegration. Sea ice begins to diminish in strength at approximately 10°F—the approximate temperature at which the ice begins rapid disintegration.

This discussion of heat transference applies only to ice formed during one season, without intermittent and alternate thawing and refreezing periods. In nature, the process is much more complicated. The important thing to remember is that *ice grows from the bottom and may also deteriorate from the bottom.* Ice also deteriorates from the top.

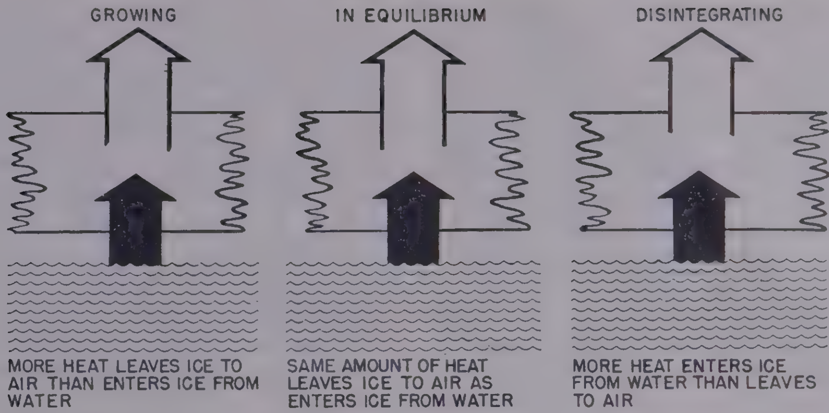


Figure 22. Diagrams showing heat flow through an ice layer when growing, when in equilibrium, and when disintegrating.

b. *Effect of Snow Cover.* A layer of snow on the ice acts as a remarkably efficient insulator that retards both the growth of the ice and its later disintegration. Table 2 lists the insulating effects of different types of snow cover on ice.

Table 2. THERMAL INSULATING EFFECTS OF DIFFERENT TYPES OF SNOW COVER ON ICE

Type of Snow	*Normal Density*	*Snow Cover Insulation per Ince Equivalent to Ice Layer (in Inches)*
Freshly fallen snow	0.10	70
Slightly settled snow	0.15	35
Normal snow cover	0.20	20
Old snow	0.25	12
Hard-packed snowdrifts in the arctic	0.35	6
Windswept snow cover during extreme cold (arctic)	0.40	5
Artificially compacted snow	0.45	4

Note: Snow cannot be compacted much above 0.5 density without considerable effort.

A layer of compacted snow (density approximately 0.5) 2 to 3 inches thick does not seriously retard the growth of the ice cover; it still will afford enough insulation to retard the effect of higher air temperatures and delay ice deterioration in the spring. A 2- to 3-inch snow layer has the added advantage of giving the ice some insulation against rapid changes in air temperature. A rapid temperature change causes stresses in bare ice, which can crack it easily. The same temperature change, *over a longer period of time,* allows plastic flow to relieve the stresses and lessen the likelihood of cracking.

c. *Forecasting Ice Growth.* For preliminary considerations and long-term planning of operations on ice, it is necessary to have some estimate of ice thicknesses to be expected in a given region at a given time of the year. Seldom are long term ice-thickness observations available for a given theater of operations—nevertheless, an estimate must be made as to the feasibility of landing a given type of aircraft on the ice at given times throughout the year.

(1) *Degree-Days As Basis for Measuring Ice Thickness.* A degree-day is a convention used by engineers to relate environmental temperatures to heat transfer. A degree-day below freezing is one day with a mean temperature of 31°F. A day with a mean temperature of 0°F is equivalent to 32 degree-days below freezing. A 10-day period with a mean temperature of 10°F is

equivalent to 220 degree-days below freezing. ($32° - 10° = 22°$; $22° \times 10$ days $= 220$ degree-days below freezing) The mean temperature for any period may be used. Ideally, the temperature used should be the air temperature at the surface of the ice, but this value is seldom available; and, if not, the temperatures recorded at the meteorological station closest to the intended site should be used.

(2) *Computation of Degree Days.* The thickness of ice for any date can be estimated by using climatic data to compute the accumulated degree-days below freezing at that date, and then solving equation (1) below.

Equation (1): $h_i = A\sqrt{S}$ where:

h_i = ice thickness in inches

A = coefficient allowing for snow cover, stream flow, and other local conditions (see table 3)

S = accumulated degree-days since freeze up in degrees F below freezing (32°)

This equation was developed originally for fresh water ice, but it can also be applied as a first approximation for sea ice. Mean temperatures should be used. The date of freeze-up itself depends mainly on the size of the body of water and the flow velocity. For a rough approximation, S in this equation is based on the freezing point of fresh water (32°F). For a more detailed analysis, use the freezing point of sea water (around 29°F) as the base temperature.

Table 3. VALUES OF "A" FOR USE IN EQUATION (1) *

A	*Conditions*
0.95—0.90	Practical maximum for ice not covered with snow
0.80—0.75	Arctic sea ice first approximation
0.80—0.70	Medium-sized lakes with moderate snow cover
0.70—0.65	Bays with brackish water
0.65—0.58	Rivers with moderate flow

* These values are based on climatological averages and may vary considerably from year to year, mainly because of changing snow conditions. The equation, therefore, can be used only for general planning and preliminary purposes and not as a substitute for ice surveys for specific operations in the field.

(3) *Some Rules for Forecasting Ice Thickness.* A simple equation for forecasting ice thickness has already been given. In addition, operational requirements will often generate a need for forecasts of ice growth. These forecasts can be used in evaluting the capabilities of a given site to handle heavier aircraft or increased traffic.

(a) Ice growth can be accelerated by snow removal, but survey parties at advance sites seldom will have snow-removal equipment at hand. In such cases, the best forecast can be obtained by applying equation (2).

Equation (2): $\Delta t = \frac{B(1+h_i)}{32-F}$ where:

Δt = time necessary for ice thickness to increase by an increment of 2 inches

h_i = measured or estimated ice thickness in inches

F = average expected air temperature in degrees F

B = coefficient (values given in table 4)

Table 4. VALUES OF "B" FOR USE IN EQUATION (2)

B	*Conditions*
5	Ice not covered with snow
7	Arctic sea ice first approximation
8	Medium-sized lakes with moderate snow cover
10	Bays with brackish water
12	Rivers with moderate flow

Example: It is proposed to utilize a given lake as a landing field. An advance survey party measures an ice thickness of 16 inches; the aircraft requires 22 inches. The expected mean air temperature is 12°F and B = 8. We apply equation (2) as follows:

From 16 to 18 inches $\Delta t = \frac{8(1+16)}{32-12} = 6.8$ days

From 18 to 20 inches $\Delta t = \frac{8(1+18)}{20} = 7.6$ days

From 20 to 22 inches $\Delta t = \frac{8(1+20)}{20} = 8.4$ days

Total = 23.0 days

If information on the depth of the snow cover is available, the following equation can be used:

Equation (3): $\Delta t = \frac{3.6(1+h_i+rh_s)}{C(32-F)}$ where:

r=equivalent ice thickness giving the same insulation as 1 inch of snow. See Table 2 for these values.

Table 5. VALUES OF "C" FOR USE IN EQUATION (3)

C	*Condition*
1.0	For ideal conditions, an open windswept lake
0.80	Sheltered lake
0.75	Open river with moderate flow
0.60	Sheltered river with moderate flow
0.30	Open river with rapid flow
0.25	Sheltered river with rapid flow

h_s=average expected snow depth, inches

C=coefficient, depending on velocity of stream flow and degree of sheltering of the water body from wind (table 5)

Example: An advance survey party measures an ice thickness of 26 inches on a slightly sheltered lake; the aircraft requires 32 inches. The snow cover is 3 inches and is expected to increase to 4 inches. The average expected temperature is 0°F. C=0.90 and r=12, according to tables 2 and 5. We apply equation (3) as follows:

$$\text{From 26 to 28 inches } \Delta t = \frac{3.6(1+26+12\times4)}{0.90(32-0)} = 9.4 \text{ days}$$

$$\text{From 28 to 30 inches } \Delta t = \frac{3.6(1+28=12\times4)}{0.90\times32} = 9.6 \text{ days}$$

$$\text{From 30 to 32 inches } \Delta t = \frac{3.6(1+30+12\times4)}{0.90\times32} = 9.9 \text{ days}$$

$$\text{Total} = 29.0 \text{ days}$$

Faster freezing can be achieved by compacting the snow to 2 inches with a density of 0.50 (r=3). In that case the required time is:

$$\text{From 26 to 28 inches } \Delta t = \frac{3.6(1+26+3\times2)}{0.90\times32} = 4.1 \text{ days}$$

If this calculation is repeated for the other increments, the total will be 4.1+4.4+4.6=13 days—thus operations may begin 2 weeks earlier. The computed values can be only approximate since the growth of ice depends on a number of factors that cannot be accounted for without special investigations. Equation (3) cannot be applied, if slush forms on top of the ice cover.

(b) Both the U. S. Navy Hydrographic Office and the Snow, Ice, and Permafrost Research Establishment (SIPRE) have developed more precise methods of forecasting ice growth and deterioration than those given above, but, as they are also more complicated, they have not been included in this manual.

d. *Artificial Growth:*

(1) *Airfield Flooding.* With the air temperature constant, ice grows fastest when it is thinnest. Engineers have tried to take advantage of this fact by flooding ice airfields, thus increasing the thickness of the ice from the top surface upward rather than by nature's method of growing from the bottom surface downward.

(2) *Feasibility Demonstrated by Finns in World War II.* The Finns used this technique in building ice airfields and roads in a few days on rivers and lakes where the natural growth of ice might never have reached the thickness needed. Experiments have shown that the growth of sea ice can also be accelerated by flooding, but airstrips

constructed in this manner have not yet been tested adequately in actual operations. At present, the Department of Defense has no pumping equipment designed especially for flooding ice strips.

Figure 23. Photograph of Point Barrow ice strip built by flooding.

9. Land Ice

The preceding discussion of engineering considerations deals almost entirely with floating ice. Land ice, as shown in paragraph 3, is also used for aircraft landing strips. Land ice does not present the same problems as floating ice. The main problems are snow removal during the winter and drainage during the thaw season. Although land ice is not as strong as concrete, it is strong enough—because of its great thickness—to support any aircraft now used or likely to be used by the Air Force.

Chapter 3

OPERATIONAL CONSIDERATIONS

10. Published Criteria for Planning and Selecting Airfields

The problems of planning and selecting airfields are not peculiar to ice and are covered in other Air Force publications, such as:

a. *AFR 86-1,* "Installation Planning and Development—Lateral Airfield Clearance Criteria."

b. *AFR 86-3,* "Installation Planning and Development—Criteria for Determining Obstructions to Air Navigation."

c. *AFR 86-5,* "Installation Planning and Development—Aircraft Movement and Approach Area Criteria for Permanent USAF Airfields."

d. *AFM 400-5,* "USAF Logistical and Operational Planning Manual."

e. *AFM 86-3,* "Installation Planning and Development."

11. Planning of Air Operations on Ice Surfaces

Air operations on ice surfaces require three phases of advance planning.
These phases are given below.

a. *Phase I. Situation Analysis.* Geographical and climatological data are studied to select sites suitable for airstrips and to estimate the probable ice conditions at these sites during the operating season.

b. *Phase II. Plans for Survey Team.* Transportation and logistics support for ice survey teams is planned in detail.

c. *Phase III. Plans for Establishment of Strips.* Logistics plans are made for establishment of airfields at the selected sites. These plans include movement of men and equipment to the sites, and the preparation and marking of the strips necessary for use in the planned operation.

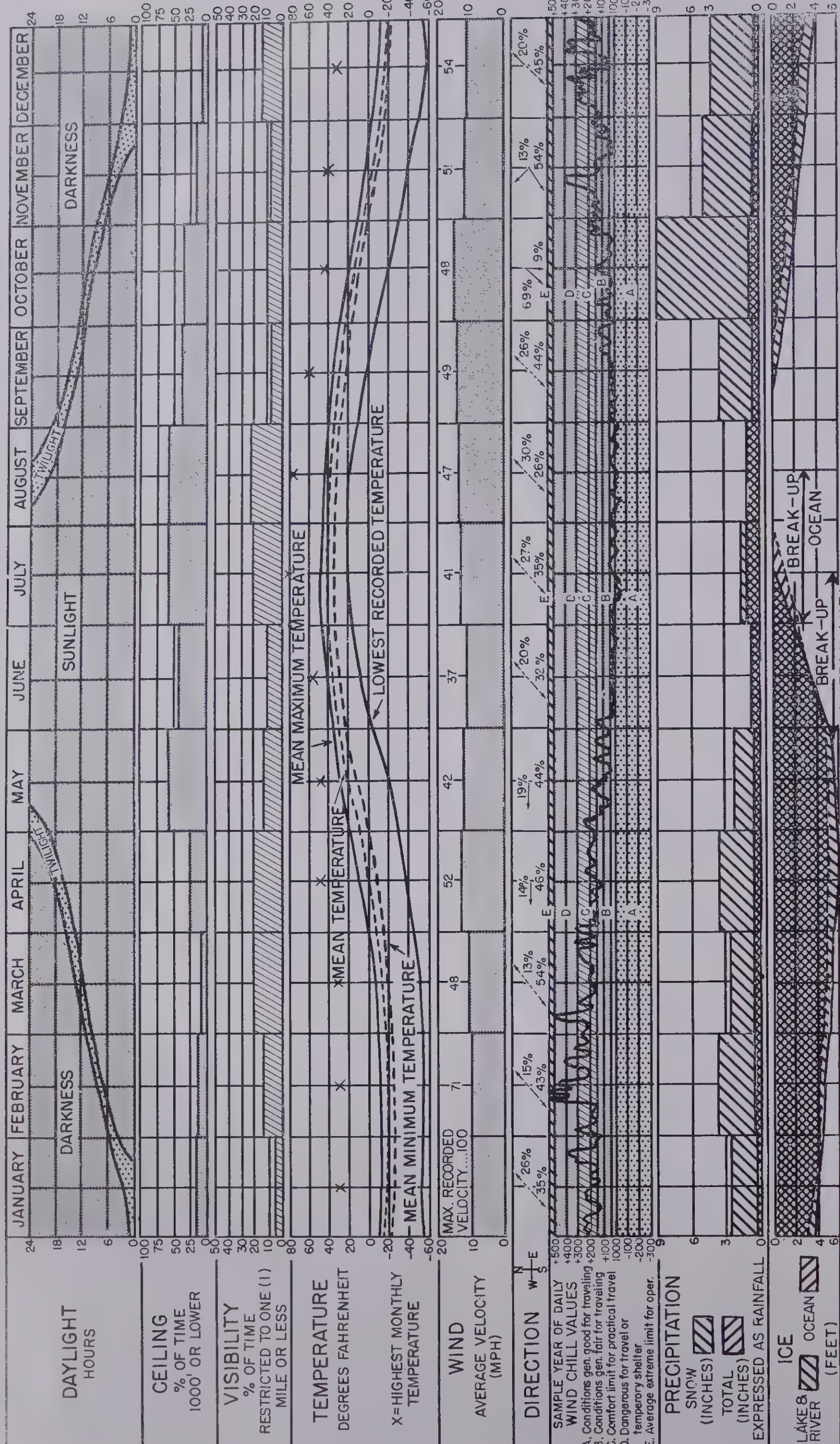
12. Situation Analysis

Preliminary study of the environment is mandatory, if later developments are to go smoothly. The study includes the following steps: First, study the ice records to determine whether ice is likely to be present when and where it is needed; second, search the climatological records for temperature data by which ice thicknesses can be forecast; third, prepare an operational feasibility chart, such as the one in figure 24, which will indicate the probable weather and natural illumination during the ice reconnaissance and operational phases. (The chart illustrated is for a full year. In most cases, coverage from November through June will be adequate.) The fourth step is to select the sites to be inspected by the ice survey teams, by study of large scale maps (scale at least 1:500,000; 1:250,000 is preferred) and aerial photographs.

13. Data Sources

a. *Weather.* Appendix 2 lists publications giving hydrographic, geographic, and climatic data on the arctic. Additional information on ice conditions can be obtained from the U. S. Navy Hydrographic Office, and, on climate, from the Air Weather Service. The Aeronautical Chart and Information Center can provide maps and photographs of specific areas.

b. *Duration of Daylight.* The most accurate source of information on daylight and twilight is the "Air Almanac," but the nomogram (figure 25) can be used as a first approximation.



POINT BARROW ALASKA

Figure 24. Operational feasibility chart—Point Barrow, Alaska.

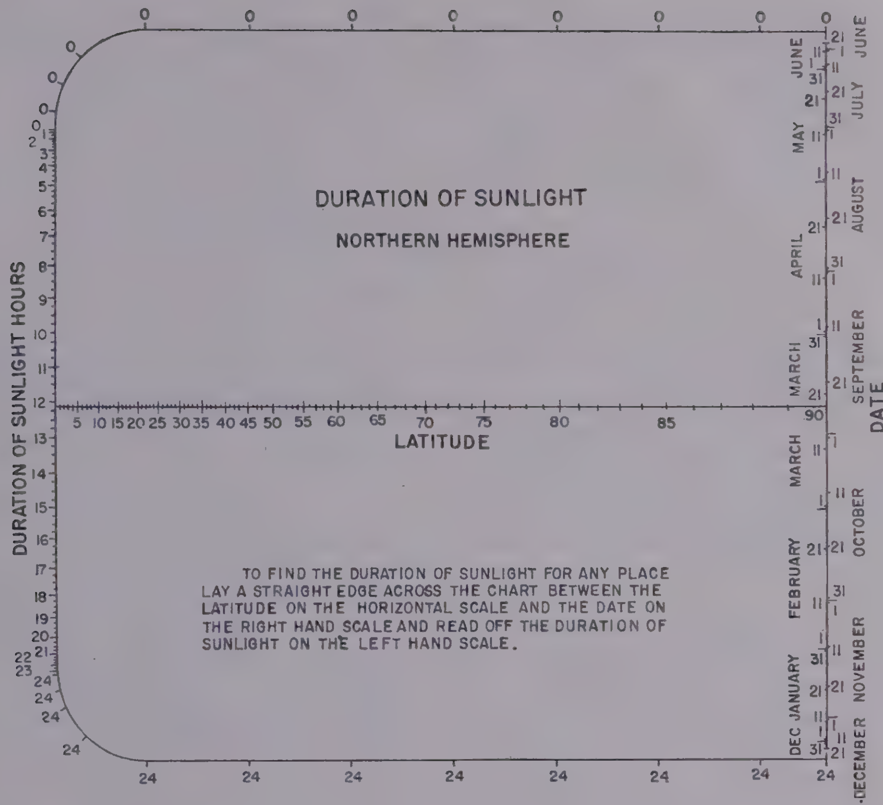


Figure 25. Nomogram for hours of daylight in arctic regions.

c. *Duration of Ice Season.* The American and Greenland arctic areas together encompass an area larger than the United States and include comparable variations and fluctuations in climatic phenomena, such as temperature, snowfall, snow cover, cloud cover, wind, and solar radiation, all of which affect the growth and disintegration of ice. The rate of ice growth depends primarily on the surface temperature of the ice sheet, its thickness, and radiation, but the rate is also influenced by wind, snow cover, and purity of the ice. All of the variables involved are likely to fluctuate so widely that ice conditions not only will vary greatly in different parts of the arctic, but will vary in the same place from one winter to the next. Therefore, any office study of ice conditions must be supplemented by on-the-spot testing. The thickness and quality of the ice govern the length of the operating season. For example, the natural growth curve for sea ice at Cambridge Bay (see figure 26), based on an 11-year temperature record, shows that the C–47 on wheels can operate from the middle of November to early June, and that the C–124 can operate from early February to early June. Artificial flooding may advance the start of the useful season by a month or more.

14. Periods When Various Types of Ice Will Be Most Useful

a. *Pack Ice:*

(1) *Polar Ice.* Polar ice may be usable shortly after freeze-up in late September or October. From mid-June to late September, thawing deteriorates the ice surface. By draining the melt water during the thaw period and, later, during freezing weather by

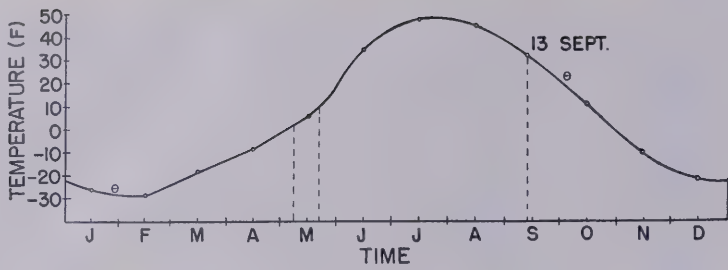


Figure 26. Chart showing temperatures at Cambridge Bay.

building up runways by flooding the period of operations may be extended.

(2) *Frozen Leads.* Frozen leads are usually smooth and snow-free, but they are weaker than polar ice and usually break up earlier. From March to June, frozen leads are plentiful throughout the pack. Aircraft operations on frozen leads after June are seldom feasible.

b. *Ice Islands.* Ice islands are massive and able to withstand ice-pack pressures without breaking up. Surface conditions are not as good in summer as in winter, because of thawing. The surface of ice islands is so uniform that melt water can be controlled with proper equipment and techniques. Braking action on *corn snow,* the coarse, granular wet snow that sometimes forms during early thaws, is good even during thawing temperatures. Ice islands may have a 12-month useful season, with operations possibly restricted slightly during the height of the thaw season.

c. *Fast Ice.* Operations on fast ice generally last only one season, because fast ice either melts or breaks up and joins the moving ice pack each summer. Its useful season may range from 2 to 9 months, depending on (1) ice thicknesses demanded, (2) local conditions, and (3) attempts to alter these conditions. Local ice conditions vary from year to year, depending on fluctuations in temperature (see figure 26), snow cover, wind, and salinity. In 1956, most fast-ice sites along the DEW line were usable for heavy aircraft from late February until early June.

d. *Lake and River Ice.* As on fast ice, operations on lake and river ice generally last only one season. DEW line experiences showed the useful season of lake ice is about the same or slightly longer than that of fast sea ice, under similar environmental conditions.

e. *Land Ice.* Ice caps, such as those on Greenland and on some of the Canadian arctic islands, show promise of having the longest useful season. Project *Mint Julep* experiences suggest that well-sited runways on the Greenland Ice Cap can probably be used all year, with some possibility that operations will be limited during the 4 to 6 weeks in midsummer when thawing affects the surface.

15. Survey Team Planning

Planning the support details for survey team operations in isolated arctic regions is far more critical than for normal operations. The planner must attempt to foresee and provide for every possible situation, with special consideration for:

a. *Logistics Support.* This support includes the special equipment and spare parts for maintenance of aircraft, the auxiliary equipment, and the survey equipment in the field. The drills, ice chisels, measuring devices, shovels, thermometers, and other equipment needed for ice survey are not standard-issue items. The special kits designed by SIPRE must be ordered several months in advance of the survey.

b. *Personal and Emergency Equipment.* The survey party should have sufficient equipment and supplies to allow the entire party to camp out for 10 days. Cooking equipment, fuel, food, sleeping bags, and

shelter must be adequate for use in −65°F temperatures.

c. *Personnel Selection and Administration.* Survey party personnel should be trained in extreme cold survival techniques and be experienced in living and working in cold weather. A working knowledge of arctic ice and snow conditions and terminology is essential to all members of the party. If it should be necessary to test ice strength, the services of skilled ice physicists must be available.

d. *Communications.* Communications channels and procedures must be planned and equipment provided.

16. Logistics Planning for Initial Establishment of the Ice Airfield

Plans for initial preparation of the ice runways and for their support and maintenance facilities must be completed in detail well in advance of the operation, to allow for procurement and delivery of equipment and supplies. The major task confronting the planner is to provide for removal of the snow cover from the airstrip surface. In many locations, snow depth and roughness will prevent wheel landings by aircraft large enough to transport the heavy snow-removal equipment normally used. In the past, the required snow-removal equipment has been air delivered in two ways:

a. *Light Tractors.* C–47 aircraft *on skis* carried in light tractors which cleared a strip long enough to allow a larger aircraft, carrying heavy snow-removal equipment, to land.

b. *Heavy Tractors.* When light tractors were unable to prepare a satisfactory strip for a one-time landing by a heavy aircraft, heavy tractors were dropped by parachute.

Personnel who plan logistics support must be experienced in extreme cold-weather field conditions or be assisted by cold weather specialists. The importance of early planning and procurement of equipment for initial snow removal cannot be overemphasized; the success of the entire operation hinges upon this action. All support facilities to be used in preparing the site for operation must be transportable by air. All materiel must be suitable for extreme cold temperatures and outdoor storage during the initial establishment of the site. Insulated field shelters that are easy to erect and heat, such as the Jamesway field shelters, are essential.

17. Aerial Reconnaissance

a. *Terrain Evaluation.* Before the best place for an ice airstrip can be determined definitely, proposed sites must be inspected from the air to evaluate the topography of the approach zones and, from the surface, to evaluate the suitability of the ice. Unless a ground party is already at the site, the aircraft carrying the ice survey team usually makes the aerial reconnaissance and combines the terrain evaluation with an aerial inspection of ice conditions.

b. *Weather for Aerial Ice Strip Reconnaissance.* Evaluation of ice conditions from the air requires daylight, good visibility, and clear skies. The operational feasibility table (figure 24), shows when these conditions are most likely to occur. The ice-survey aircraft should not attempt a landing, except where the degree-days' computation (see paragraph 8c (2)) indicates ice of approximately twice the minimum thickness needed for emergency operation of the aircraft.

c. *Aircraft for Aerial Ice Strip Reconnaissance.* An aircraft used for aerial ice strip reconnaissance should have:

(1) Long range.

(2) Good handling characteristics at low flying speed.

(3) Ski-wheel landing gear.

(4) An internal heat source.

(5) Good cold-weather performance with minimum maintenance.

(6) Adequate navigation equipment.

The C–47 on skis has been the aircraft used most for ice survey work. The reconnaissance aircraft, its crew, and the ice survey team should be a self-sufficient unit while at the base during the period of the survey. They should be independent of base facilities, except for fuel and oil, quarters, and rations.

d. *Personnel for Aerial Reconnaissance.*

Figure 27. C–47 on skis.

Each ice survey team should consist of at least two men trained in ice-measuring and in evaluation techniques, and one of the men should be a pilot current in the type of aircraft that will use the strip.

(1) *Teamwork Essential.* The aircrew and the survey unit are a team, each part of which has its function. Generally, the aircrew will be working while the ice survey team is resting, and vice versa. It should be understood that the two will assist each other when it is important to do so. Whenever possible, the same survey team and the same aircrew should be kept together.

(2) *Training and Experience Requirements.* All personnel should be well trained in extreme cold-weather working and living. Aircrews should be experienced in field operations and maintenance with minimum facilities.

e. *Aerial Indications of Ice Characteristics.* The U. S. Navy Hydrographic Office's publication, "Aerial Ice Reconnaissance," 2nd edition, 1956 (see appendix 2), should be carried by each ice survey team, because this document contains instructions on observational techniques. Although an aerial view of ice seldom gives enough information to determine whether the ice is suitable for heavy aircraft, an experienced observer can learn quite a bit about the ice from aerial observation. Some of the physical characteristics of the terrain, as seen from the air, are described below.

(1) *Color.* As an indicator of ice conditions, color is unreliable, especially from the air. Thin sea ice is dark in color and gets whiter as it grows thicker, but a snow cover makes thin and thick sea ice appear uniformly white from the air. Wind-swept

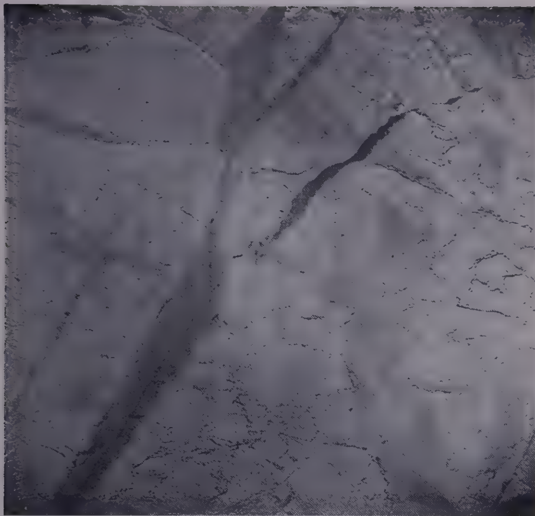


Figure 28. Thin and thick ice from the air.

lake ice may be very thick and still be dark in color.

(2) *Smoothness.* On a clear calm day, with the sun shining at a low angle, surface irregularities in the ice can be seen from the air. On an overcast day without shadow, even large drifts and hummocks are difficult to see.

(3) *Thickness.* The thickness of the ice can sometimes be estimated from the exposed edges of the rafted ice. An airborne penetrometer, which is intended to give a reading of ice thickness when dropped from

Figure 29. Sastrugi—wind-deposited and wind-eroded irregularities.

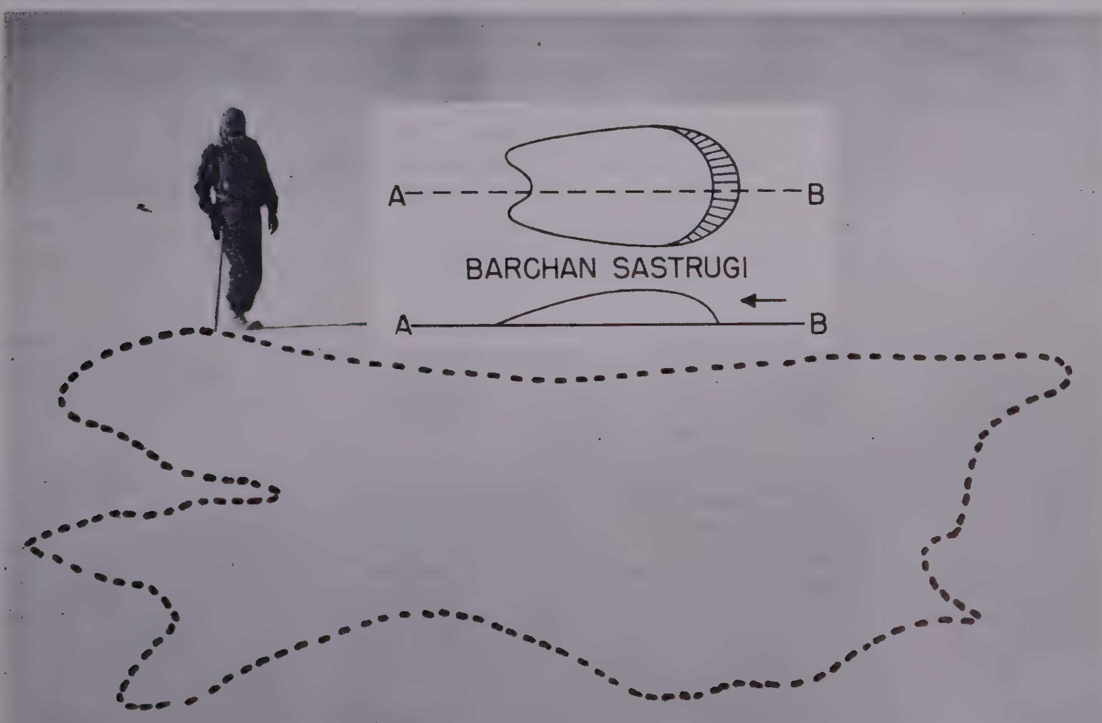


Figure 30. Barchan drifts—diagram and photograph.

a survey aircraft, is under development. This device has not yet been perfected.

(4) *Prevailing Wind.* Snowdrifts and wind furrows in the snow are indicators of the direction of past winds.

f. *Exploratory Survey.* On the exploratory survey the survey aircraft should circle above the proposed site several times. The survey team should sketch the coastal configuration, approaches, location of rafted ice, leads, and any other features of interest. If a surface survey is decided upon, the first landing should be touch-and-go. Unless a ground party has already determined that a safe ice thickness exists, the aircraft should land only when the degree-days' computation indicates an ice thickness of approximately twice the minimum needed for emergency operation.

18. Ground Reconnaissance

a. *Basis for Final Selection of Site of Airfield.* Although aerial photographs and large-scale maps provide much valuable information for site selection, the final selection must be based on a surface inspection of the proposed site. Untrained personnel have a tendency to select sites which are kept clear of snow by the wind. Such sites on fast ice and lake ice are usually in the lee of a terrain obstruction and, to take advantage of the cleared area, the runway must be oriented at right angles to the prevailing wind. Obviously, most landings on such a strip will be crosswind, often in turbulent air, and especially dangerous on glare ice.

b. *Requirements for Acceptable Site.* Ice should be smooth and in no place less than the minimum required thickness throughout the runway and parking area. It should be supported by deep water, be free of wind-blown sediment or other foreign materials and preferably without wet cracks and holes, and be likely to last for the duration of the operation.

(1) *Strongest Ice—Best Location.* The best location for an airstrip, as far as the strength of the ice is concerned, is on smooth ice over deep water. It should be no closer to the shore or shelf ice than twice the influence radius distance (see table 1). The best orientation is at an angle of between 45° and 60° to the shore. Ice frozen to the bottom should be avoided even though it is of suitable thickness, because, without the support of the water, humps and hollows will develop and the ice will crack and become very rough after a few landings. The only possible exception to this rule would be a situation where the ice is resting on a mud bottom that gives uniform support.

(2) *Ample Room Essential.* The site selected for an airfield should allow clear approaches and adequate terrain clearance for aircraft in the normal traffic pattern. It should have ample room for the runways and parking areas needed for the operation being planned.

Chapter 4

LOCATION OF THE ICE AIRFIELD

19. Choice of Site for Airfield

a. *Favorable.* Sheltered bays and lagoons provide the best airfield sites, because they are protected from horizontal pressures from the moving pack ice and from coastal currents. The ice should be floating free of the bottom at low tide, as the deeper water minimizes the effect of resonance waves.

b. *Unfavorable.* Topographic hazards to avoid are tidal cracks between the floating ice and the grounded ice; thin spots caused by currents, thick snow deposits, up-welling of warmer water; and seal holes and other air pockets. Wide leads with open, steaming water at the edge of fast ice are a common occurrence in some parts of the arctic. They open and close depending on the direction of the wind. Fog rising from the leads may impair visibility; therefore, runways should be oriented to avoid an approach over an open lead whenever possible.

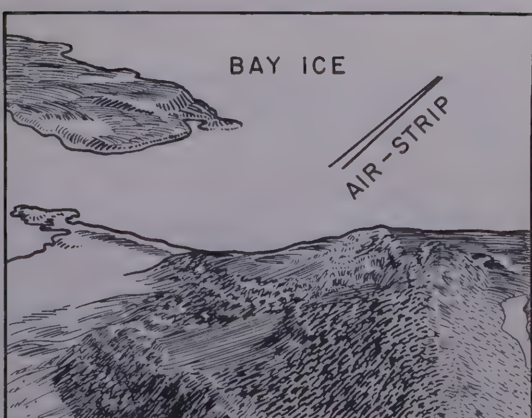


Figure 31. Diagram of airfield on fast ice showing optimum location and orientation.

20. Ice Types and Behavior

a. *Movement—Horizontal and Vertical.* Ice is subject to horizontal and vertical movement. In general, the airfield should not be located on ice that is subject to horizontal movement. Such movement is sometimes indicated by rupture points—slight elevations of four corners formed by intersecting cracks. Eventually, horizontal pressure will raise these corners up to 10 feet, causing peculiar formations that should not be confused with hummocks formed by pieces of ice stranded on shallow places. Hummocks are even higher and wider ice formations and may be several years old. Hummocks are not a sign of horizontal pressure. In fact, excellent airfields sometimes can be established on deeper water behind a line of ice stranded on a reef.

b. *Ice on Water:*

(1) *Fast Ice.* Fast ice forms along coasts and in protected areas such as bays, lagoons, and fiords. It is either attached to the shore or confined, so that it remains in place until the summer breakup. *Winter ice* is ice one year old or less and is smoother than *polar ice* which is ice more than a year old. Ice in deep harbors with steep shore gradients tends to clear out of the harbor completely on breakup. In such harbors, the ice will usually be smooth. Ice in shallow harbors is seldom as smooth, and often does not clear out completely.

(2) *Pack Ice.* Colonel J. O. Fletcher, USAF, who established the first station on the *ice island* T-3, says of the arctic pack ice: "It is safe to say that literally thousands of excellent runway sites are available in winter on the drifting pack. Many of them

are clear of snow and require no improvements for wheel operations."* Size of floes, depth of snow cover, distance between pressure ridges, and open leads are the factors to be considered in siting airfields on the pack.

(a) Approximately 5 to 10 percent of the ice pack is composed of *floes* with surfaces suitable for establishing ice runways. *Old floes* composed of polar ice 2 or more winters' old are more desirable, because they are thicker and stronger and much less likely to break up than the floes of winter ice. Old floes may be as much as 10 miles long, but are often rough and hummocky and may be unusable or require considerable work before their surfaces are smooth enough for wheel landings. Once established, a runway on an old floe can be kept operational throughout most of the year, although surface thawing will interrupt operations in mid-summer.

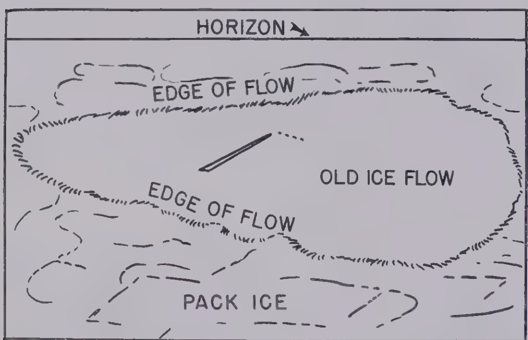


Figure 32. Sketch of airstrip on an old ice floe.

(b) *Leads* form throughout the pack at all seasons of the year, because of the wind-induced movements of the ice. They generally freeze over in winter and make excellent landing surfaces. Snow cover on leads is usually sparse, ranging from 1 to 5 inches with some scattered drifts up to 18 inches deep. Ice in leads varies in thickness according to its age; it may be only a few inches thick, but can be from 60 to 72 inches thick, which is more than adequate at the prevailing winter temperatures for unrestricted operation of aircraft of up to 200,000 pounds. Runways 10,000 feet in length in frozen leads have been used during actual operations on the arctic pack. Leads may be as much as 3,000 feet wide, which allows ample space for parking and servicing of aircraft when the runway is in use. Open water sometimes occurs within an otherwise frozen lead. Fog will form over these water surfaces and drift downwind, and may interfere with visibility.

(3) *Ice Islands.* The great thickness (100-150 feet) of ice islands makes them almost immune to the pressures which split floes and produce leads. An ice island is the safest possible location for an airstrip on the arctic pack. The surfaces of ice islands are rolling ridges about 1,000 feet apart separated by shallow troughs. The depth of these troughs varies from a few inches to several feet. Some troughs are so shallow that they will not interfere with wheeled landings made at right angles to the ridges. In midsummer the troughs accumulate melt water which hinders aircraft operations. Freezing of this melt water in the fall produces a smooth, hard surface capable of supporting the heaviest aircraft. Airstrips on the ridges can be kept operational the year around by snow clearance in the winter and draining and scraping in the summer.

(4) *Lake Ice.* Medium-sized lakes 2 to 10 miles in diameter usually make better ice-runway sites than larger or smaller lakes

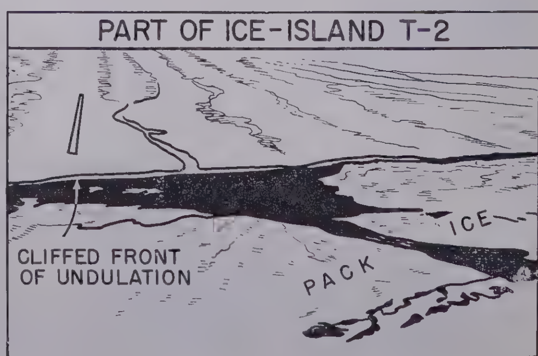


Figure 33. Diagram of airstrip on an ice island—parallel to the ridges.

* Fletcher, J. O. Col., USAF, "Employment of Air Forces in the Arctic Ocean Area" (Thesis) AC&SS, May 1954 (Secret).

do. Currents and turbulence in the larger lakes cause undesirable ice movement and may produce a rough surface. Small lakes may not have enough ice surface over deep water to permit a satisfactory runway orientation. Very shallow lakes are undesirable regardless of size, because the ice will freeze to the bottom and crack under loads that a floating ice sheet of the same thickness would support. The ice layer should be floating free of the lake bottom. When thawing, fresh water ice may separate into vertical prisms while still quite thick. This ice, known as *candle ice*, has practically no load-bearing capacity.

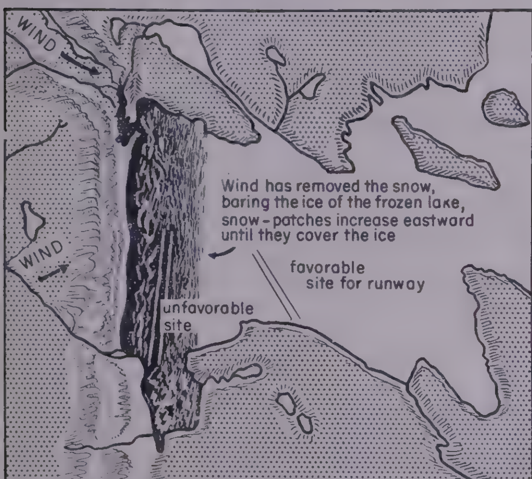


Figure 34. Diagram of airstrip on a fresh water lake.

(5) *River Ice.* Ice-covered rivers seldom make good airstrip sites. The thickness of river ice varies greatly over very short distances. Ice over fast-flowing water is often thin and weak, especially where the river bed is shallow. Ice under snowdrifts may be weak. Ice on cut-off meanders and backwaters offers the same disadvantages as that in shallow lakes. A width of twice the influence radius produces undesirable resonance. A narrower width or, in some cases, a wider width, is preferred. Candle ice is not as common on rivers as on lakes, but it is a potential hazard.

(6) *Thickness Measurements on Floating Ice.* After the airstrip site has been tentatively selected, the ice thickness should be measured by means of the SIPRE ice-thickness kit shown in figure 36, or its equivalent. Use of the one-inch (diameter)

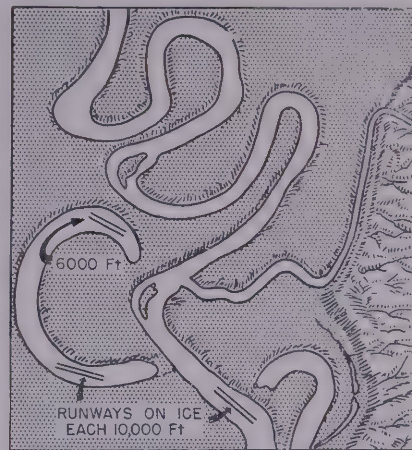


Figure 35. Diagram of airstrip on river ice on broad river showing weak ice areas and a cut-off meander.

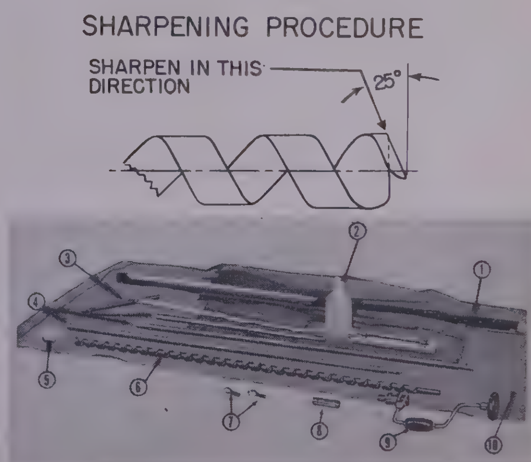


Figure 36. Instruction sheet for SIPRE ice thickness kit.

auger included in the kit will not show the thickness of *snow ice*, the relatively porous material often lying on top of the ice. The SIPRE method of determining the ice thickness requires that only one-half the thickness of snow ice and from one-third to two-thirds its thickness in salt-water ice be counted to

obtain the total ice thickness (see appendix 4). A pit should be dug by which to measure the snow ice thickness, or a core should be obtained with a three-inch (diameter) coring auger.

(a) Ice thickness should be measured in at least six widely separated points on the runway and parking area. The first hole should be drilled in the proposed parking area or wherever the aircraft will stop to unload. If the thickness is less than required, the location should be rejected and a search made for thicker ice. If the ice is the required thickness at the first hole, the warm-up area, taxiways, runway—especially the turnabout area—points of propeller reversal, and about 100 feet ahead of the touchdown point should be checked. (A minimum of two parking areas should be selected for alternate use, to allow the ice to regain its strength.) If the ice is close to minimum thickness, additional measurements should be made about 400 feet apart for the length of the runway to make sure that there are no thin areas. Thin areas are most likely to occur under snowdrifts, over shallow water, and near points of land. An acceptable ice strip must be above minimum required thickness *at all points.*

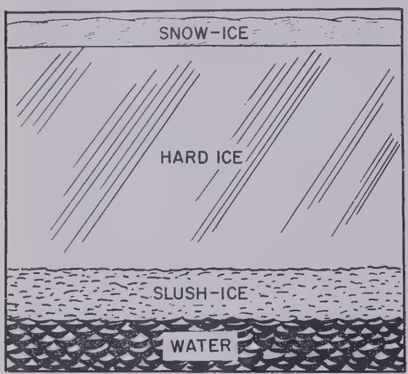


Figure 37. Diagram of cross section of ice sheet showing slush layer, hard ice, and snow ice.

(b) The runway and parking areas should be reconnoitered on foot. The vicinity should be charted indicating the relationship of the strip to points of land, pressure ridges,

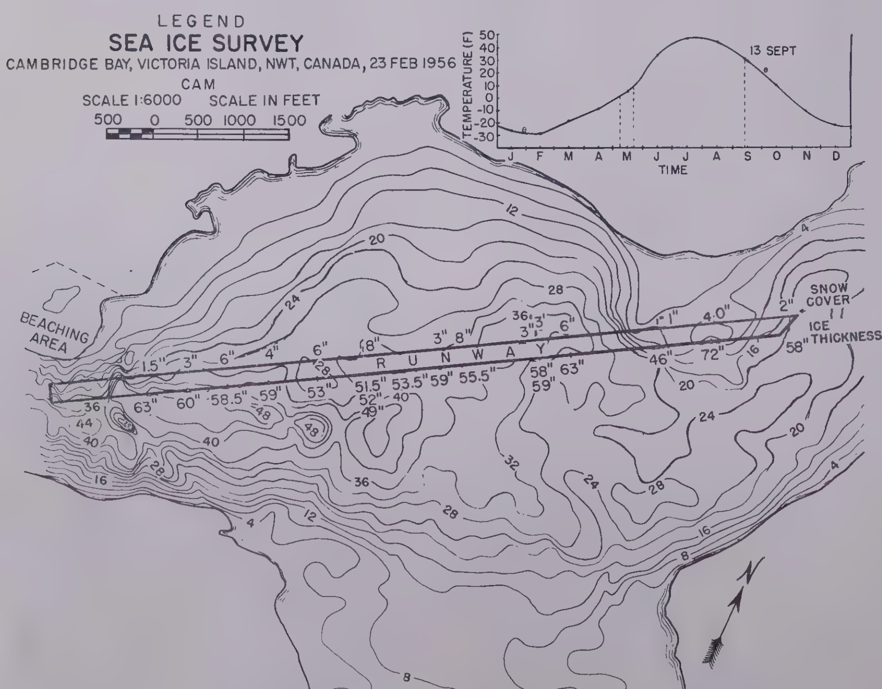


Figure 38. Diagram showing measurements along runway of marginal thickness.

and hummocks, and showing the location of all cracks on the strip over $1\frac{1}{2}$ inches wide. The depth of the snow cover should be recorded and temperature readings taken at the surface of the ice under both the minimum and the maximum snow cover. The measurements and sketches derived from the exploratory survey should be transferred to the ice-airfield journal as soon as possible (see paragraph 22).

c. *Ice on Land:*

(1) *Ice Shelves.* Normal operations off the natural surface of the Ellesmere Ice Shelf are possible for probably 10 months of the year. In midsummer, melt water and slush require constant draining and scraping of the runways to keep them operational. Ice shelves in the arctic are of the same type of ice as ice islands, with the same undulating surface. The problems of runway-site selection are very similar—the limiting factors in siting strips on an ice shelf being the orientation of the ridges and the presence of crevasses. The *firn* of the antarctic ice shelves will not support wheeled aircraft, without extensive reworking and compacting by special equipment. It is not known whether strips can be prepared by removing the firn to expose *glacial ice.* Antarctic ice shelves usually have more crevasses than those in the arctic.

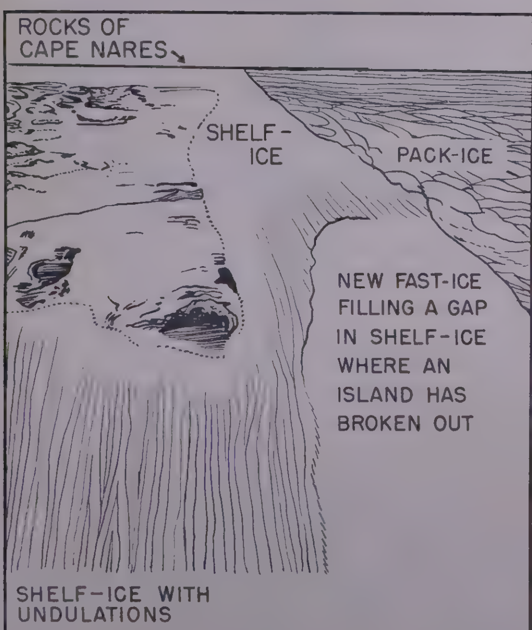


Figure 39. Ellesmere Ice Shelf.

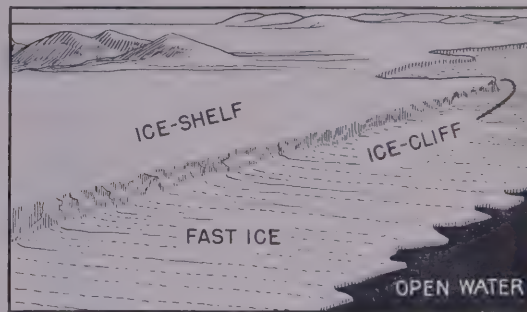


Figure 40. Ross Ice Shelf in the antarctic.

(2) *Ice Caps.*

(a) Although airstrips capable of supporting wheeled aircraft have been constructed on the firn of the Greenland Ice Cap, the techniques and equipment used are still experimental and will not be discussed in this manual. Natural landing fields for wheeled aircraft in Greenland are restricted to the basal glacial ice with thin snow cover and to frozen lakes. These conditions are found only in a belt about 10 miles wide in the margin of the interior plateau, just above and below the *firn limit* (the lowest position of the permanent snow cover of the ice cap). In this belt, the snow melts each year and exposes hard, crevasse-free glacial ice. Above the firn limit, the snow cover is permanent—below it, the ice is crevassed and broken. Crevasses occur in many places throughout and above the firn limit, while other places have large areas of smooth, crevasse-free ice. On any glacier or ice cap the principal hazard is crevasses. Airstrips should not be located in a crevassed area.

(b) The best sites for strips on basal ice are on the low ridges, between the shallow valleys that are normal features of ice-cap topography. Sites with good natural drainage may possibly be usable in all seasons, with careful maintenance. At worst, they will be closed to traffic only 4 to 6 weeks

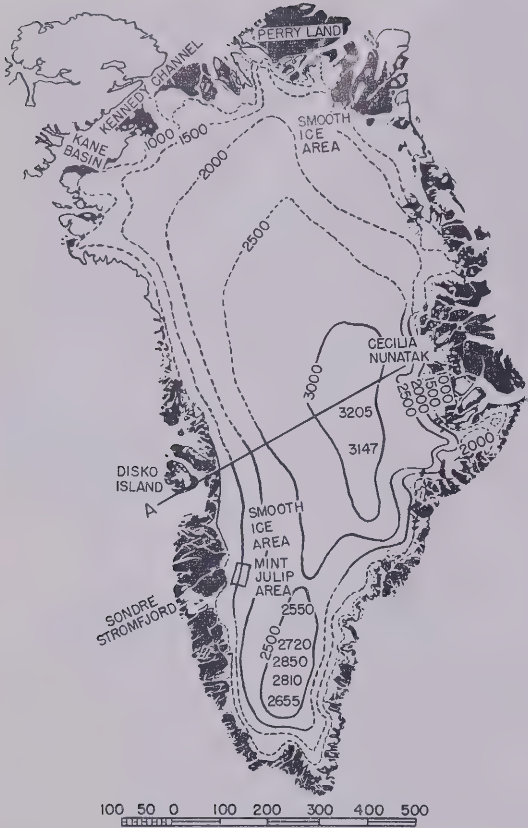


Figure 41. Outline map of Greenland showing smooth ice areas.

each year. During the cold season, which is approximately 10 months, the slush fields and melt-water lakes freeze solid and provide additional sites. Frozen slush fields are likely to have rough surfaces. If the runway is situated on basal ice there is no need for concern about its bearing capacity. Top surface observations should be made, for differential thawing may cause small channels or potholes. Roughness from differential melting may be temporarily corrected by filling and compacting loose ice or firn into the depressions. Thawing air temperatures will cause the surface of land ice to deteriorate into a shallow layer of loose ice crystals. During continued thawing temperatures this layer may become deep enough to cause rutting by aircraft wheels. If so, the loose ice crystals may be scraped off down to the solid ice beneath. This process may be repeated as necessary and indefinitely, except where the runway is situated on stratified ice and firn. In this case, the

Figure 43. Diagram of landing strip at *Mint Julep* and drainage pattern.

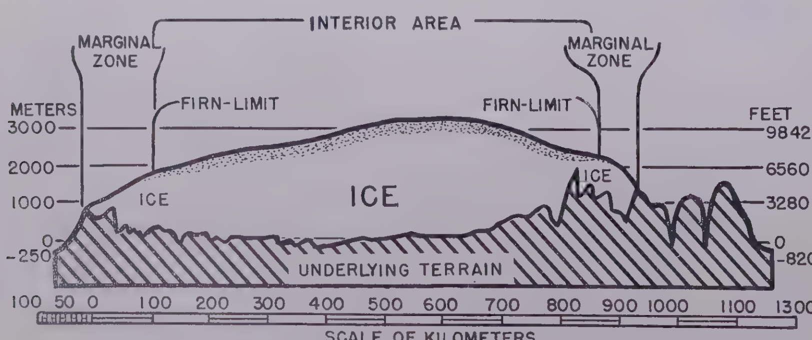


Figure 42. Cross section of Greenland at latitude 68°N.

top ice layer may become too thin to support the aircraft.

(3) *Thickness Measurements on Land Ice.* Runways selected on land ice should be sounded with an ice auger or corer to assure that the ice is a solid mass. At least 10 to 12 borings should be made at varied intervals over the entire length of the runway. Inland from the firn limit, the surface may consist of layers of ice interspaced by firn layers of far less bearing-strength than the ice. Such stratified surfaces have not been tested to determine the minimum thickness of ice required to support the different types of aircraft. However, the wheels of an aircraft might break through thin places, resulting in a ground loop or damaged gear. If the top layer of ice is 5 to 6 feet or more in thickness, it may be used safely as a runway.

Chapter 5

AIRFIELD PREPARATION, MAINTENANCE, AND OPERATION

21. Snow Removal, Compaction, and Control

Snow removal and control require most of the effort in preparing and maintaining airfields on ice. Deep, uncompacted snow on runways hinders aircraft ground operations and retards ice growth by insulation. High snowbanks on runway shoulders must be avoided. They are not only safety hazards, but also cause excessive drifting in their lees, place additional strain on the ice, and sometimes cause runways to crack. Large snowbanks on runway shoulders may be some aid to orientation, but their weight causes troughs to form on the ice surface. Snow piles should always be less than 3 feet high and never more than two-thirds the thickness of the underlying ice. Compaction of snow is preferred to removal, where snowfall and drifting are light. When snowfall is heavy, snowbanks should be graded and distributed to avoid concentrated loads on the ice. No snowbanks or snowdrifts of any height should be allowed on or near the ends of the runway, where they might be struck by an aircraft in landing or taking off.

a. *Preparation of Runway.* Early snow removal far in advance of air operations is mandatory when ice thicknesses are marginal, in order to accelerate ice growth. A 2- to 3-inch layer of compacted snow left on a runway delays ice deterioration in the warm season and aids ground control of aircraft by improving traction and braking action without seriously retarding ice growth. Loose snow must be controlled, especially at the spot on the runway where propeller pitch is reversed; otherwise, flying snow may seriously obscure visibility. Locating of runways in wind-swept sites and dragging and rolling of wind-compacted snowdrifts will lessen snow removal and control problems. As snowfall is usually less in the arctic than in subarctic and temperate latitudes, snow

Figures 44 and 45. Photographs showing right and wrong ways to pile snow along runways.

removal there demands much less effort than at U. S. home bases such as Ellsworth Air Force Base, South Dakota, and Loring Air Force Base, Maine.

b. *Maintenance of Runway:*

(1) *Healing of Cracks.* All significant cracks should be located, marked, and healed. An understanding of the factors that cause cracks will help in analyzing, interpreting, and relating cracks to ice-bearing strength (see subparagraphs 7e and 7f). Dry fractures that are more than 1½ inches wide should be healed with slush or water. Wet fractures in the ice may heal themselves overnight. Cracks frequently appear within the influence radius of large snow piles. Having alternate runways and parking aprons may insure continuous air operations, if serious runway cracks develop. All wide cracks should be marked with fluorescent red flags, so that they may be distinguished from any new cracking that might occur after the site is selected. The flags should not be removed until the cracks have healed.

(2) *Ice Inspection.* Surface irregularities may require leveling, much the same as "cut and fill" construction on land. Ice inspections should be continuous, the frequency depending on aircraft traffic and on temperature conditions. Inspections should include the detecting of new cracks, observing the condition of old ones, and identifying new snowdrifts. Ice thicknesses should be checked once weekly when temperatures are below 10°F; twice weekly when temperatures are between 10°F and 25°F; and daily or oftener, when temperatures rise above 25°F. (A new hole should be drilled for each ice check.) At the beginning of summer thaw, ice surfaces start to melt, become soft, and remain so throughout the thaw period. Melt water ponded in depressions causes ice erosion, soft spots, potholes, watersplash damage to aircraft, and generally hinders aircraft ground operations. Aircraft wheels may form shallow ruts on disintegrating ice surfaces, and prolonged parking may depress the ice surface. Both of the Soviet stations, NP–3 and NP–4, had serious difficulties with melt water and NP–3 finally had to be abandoned.

c. *Personnel and Equipment:*

(1) *Personnel.* Sufficient personnel are needed to provide crews for 24-hour operations on each piece of equipment, plus at least one foreman. On operations involving several pieces of equipment, each shift should have a foreman.

(2) *Equipment.* Equipment used in preparing and maintaining ice airfields should be simple to maintain, durable, and air transportable. On DEW-line sites in 1955, medium tractors were airdropped. These tractors were used to clear a strip for a C–119 to land with heavier equipment that cleared a strip for C–124's.

(a) The minimum equipment needed for any site is a *medium tractor* with a bulldozer blade. This tractor will clear a strip on smooth ice with a thin snow cover, but obviously the job will be done faster if more equipment is used.

(b) If snow is to be compacted, *rollers and drags* will be required.

(c) If much snow has to be moved, *rotary plows or heavier tractors* and *snow-removal equipment* will be needed. New, light rotary snow-removal equipment, which can be airlifted by C–47 aircraft on skis, is available from commercial sources. One company, in particular, has developed light, jeep-mounted rotary plows that can remove approximately as much snow as large rotary plows now being used at air bases in heavy snow areas.

(d) Flooding operations in winter and strip maintenance during thaw season will require *water pumps, fire hose, and accessories.* All such equipment should be transportable over snow.

22. Airfield Records

a. *Maintenance of Ice-Airfield Journal.* One person of the airstrip maintenance crew, preferably the officer or NCO in charge, should be designated to record daily in a journal all factors affecting the ice airfield. Data that should be recorded in the ice air-

Figure 46. Photograph of D–4 tractors towing rollers and drags.

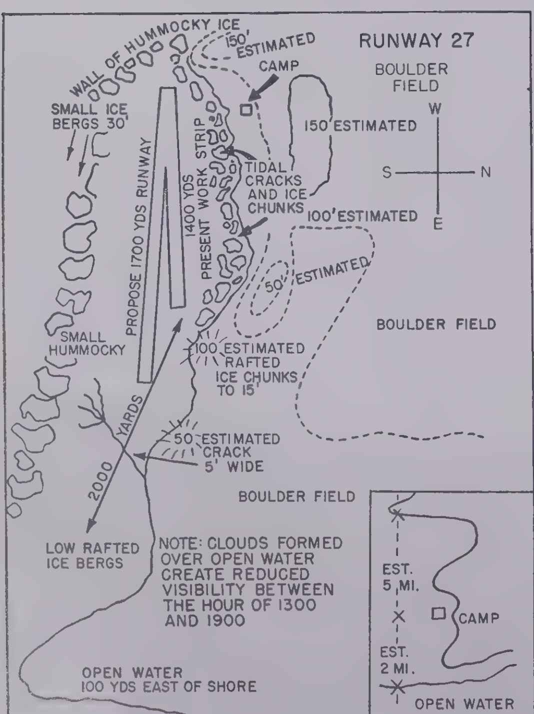


Figure 47. Field sketch—ice airfield survey.

field journal are described in subparagraphs (1) through (11).

(1) *Date and result of exploratory survey* with sketch of general situation, cracks, pressure ridges, and surrounding terrain; and note whether on sea ice in bay, pack ice, lake or river ice, and the depth of water (see figure 47).

(2) *Layout of airfield,* showing orientation and the dimensions of runway, taxiways, parking areas, and markings.

(3) *Date and procedure of* first and all subsequent *snow removals.*

(4) *Height of snow* on runway, loose or dense, height of snowpiles.

(5) *Current data on ice thickness.*

(6) *Depth of water and tide range.*

(7) *Description of crack development*—noting width (and approximate depth) of dry and wet cracks, and date and details of artificial healing.

(8) *Daily* air *temperatures* at the runway and surface temperature under the snow on the runway. The thermometer must be located in shade, preferably in a standard instrument shelter. The daily mean can be derived from the following combinations: mean of maximum and minimum; or mean

of measurements at 0700, 1300, and 2100 local time; or meean of measurements at 0030, 0630, 1230, and 1830 ZULU time. The last combination is preferable because the regular synoptic weather observations are taken at these times.

(9) *Landing and parking record*, showing the type of aircraft, gross weight, time of landing, and duration of parking on the same spot. Record and describe in detail whether any cracking under aircraft was heard or seen during taxiing or parking; note whether cracking was occasional or frequent; describe whether sagging was observed. Any incidents or unusual occurrences, especially during emergency landings, should be entered in detail.

(10) *Depth of slush on the ice* during thawing weather and the formation of potholes.

(11) *Deflection record* under or at the aircraft, if such observations were made by engineer's level. Note the place of the rod in relation to the aircraft.

The designated person, in charge of the journal, will radio changes, in the operational condition of the ice, to the main base. The making of necessary observations and documenting them in the ice-airfields journal at ice strips operating at a high frequency is a full-time job for an experienced ice observer. Sometimes ice airfields have to be used which are not under direct USAF control. In many such cases, no adequate ice airfield journal is maintained. As a substitute minimum required, an "ice landing record" should be kept by the pilots. It is a good idea to do it, even if an independent journal is kept at the site, since the pilot's comments might be very valuable. Similar records were kept for years by the former Northeast Air Command.

b. *Sample Journal.* A sample form, where the most essential information can be easily checked off and written in is given in appendix 3. The questions in this form are self-explanatory. Notes should be made (under "Remarks") as to any difficulties encountered during landing, parking, and takeoff.

c. *Ultimate Use of Airfield Journals.* Ice airfield journals and ice landings records (or copies thereof) should be mailed to the USA Snow, Ice, and Permafrost Research Establishment, 1215 Washington Avenue, Wilmette, Illinois, after completion of the operation. Such records are necessary for technical evaluation and continuing improvement of criteria for ice airfields.

23. Airfield Markings

The markings of airfields on ice must be adequate to identify the airfield and to delineate the landing and approach areas in an otherwise white, featureless landscape. Airfield markings prescribed in existing regulations for hard-surface permanent runways must be modified or augmented to meet the peculiar needs of ice airfields.

a. *Runway Surface Markings.* Sea-marker dye has been used to mark center lines of snow-covered runways and taxiways. Use of the dye is feasible during winter and early spring; however, as hours of sunlight increase and thawing begins, the surface of the runway should be bulldozed clean to remove all traces of dye. If allowed to remain, the dye will absorb heat from the sun and accelerate melting. No heat-reflecting materials, such as aluminum powder, for marking snow have been found that can be used without damaging the runway surface. Until such a material is discovered, ice-runway markings will have to be limited to the sides of the runway.

(1) *Markers.* The markers used to indicate the edges of the runway, to show the touchdown point, and other information must:

(a) Have maximum visual contrast with the white snow background.

(b) Be visible from all directions from the air.

(c) Remain free from drifting snow.

(d) Not transmit absorbed solar radiation to the snow and cause melting.

(e) Not be affected by winds.

(2) *Barrels.* The most satisfactory of all the markers tested during DEW-line operations is the common black 55-gallon metal

barrel. Comparison of the barrel with the criteria listed above shows that the barrel when placed on end:

(a) Provides maximum contrast—black against white.

(b) Presents the same visual angle viewed from any direction.

(c) Remains free of snow. The cylindrical barrel's aerodynamic characteristics are such that the wind blows away from instead of against it (see Figure 48) except when the depth of the surrounding snow exceeds the height of the barrel (36 inches), in which case snow drifts into the depression and covers the barrel.

(d) Transmits very little heat to the surface of the snow or ice.

(e) Stays in place even during high winds.

Figure 48. Photograph showing barrels free of drifting snow.

In addition to the virtues cited above, the barrel is usually available at the sites to be marked whereas other types of markers are not readily available. Spruce trees and wooden tripods have been used to mark snow-covered runways, but few ice runway sites are in wooded areas. Evergreen trees have to be flown in, using valuable cargo space, and have to be replaced frequently because of breakage. Fabricated wooden tripods also use much cargo space, and fabrication at the site requires labor that might not be available.

Figure 49. Photograph showing snow drifting over barrels lying on their sides.

(3) *Colored Markers.* Although black against white provides maximum contrast, colored markers have advantages in ice runway markings—especially in semipermanent installations. Some natural objects in the arctic—a rock outcrop, for example—may be black. A brightly colored object is obviously artificial. Also, use of colors allows identification by color code. For example, the runway could be marked with unpainted black barrels, and parking areas could be marked with barrels painted international orange.

(a) Under many visibility conditions, *fluorescent colors* can be seen at greater distances than black or international orange. The flags used for marking cracks and danger areas should be made of fluorescent cloth. Runway markers painted with fluorescent red stripes will provide additional help to pilots at times when the visibility is poor.

(b) Figure 50 shows the marking used by the Western Electric Company. This was approved by the 18th Air Force on Project 572 for runways with heavy traffic.

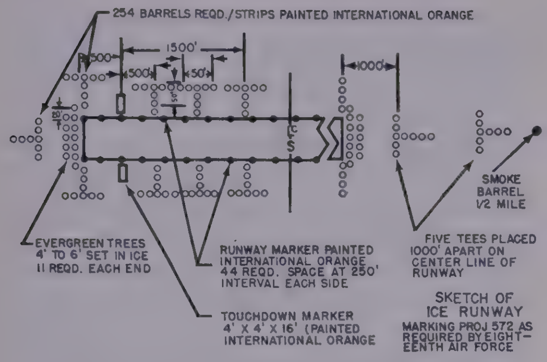


Figure 50. Runway marking used by Western Electric Company on Project 572.

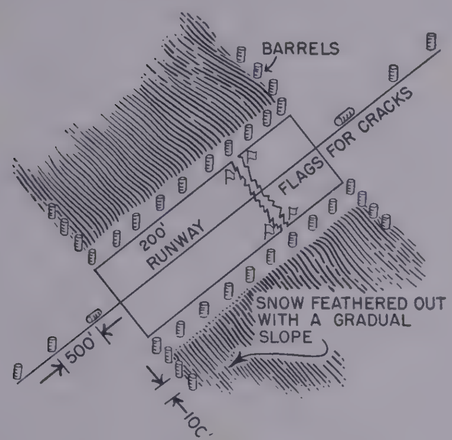


Figure 51. Suggested markings for ice runway to be used only a few times.

Figure 51 shows markings suggested for an ice runway that will be used only a few times.

(4) *Height Guidance Markers.* Landing short is the commonest cause of accidents on snow- and ice-covered strips. The monotonous landscape seldom gives the pilot enough visual cues with which to estimate his height accurately enough when flaring out. On sand and coral strips, which present the pilot with a similar visual task, the problem is sometimes alleviated by setting frangible board markers across the approach line 200 feet from the end of the runway. The boards are 1 inch by 6 inches by 4 feet and are sawed halfway through so that, if hit, they break easily without damaging the aircraft. The boards should be painted international orange or, preferably, fluorescent red for

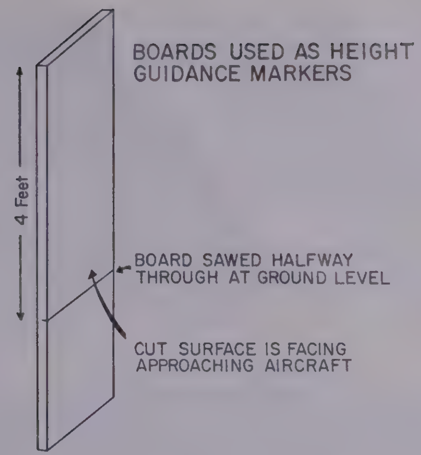


Figure 52. Diagram showing methods of cutting and setting up boards.

high visibility. Barrels and evergreen trees have also been used as height guidance markers, but barrels are not frangible and frozen tree limbs can puncture tires.

(5) *Other Markers.* When barrels are not available at a site, equivalent markers will have to be acquired. As noted previously, the making of markers at the site requires labor that may not be available. Whatever the marker used, it will have to meet the criteria listed in subparagraph a(1).

(a) *Flags* have been used as markers. They are unsuitable when the wind blows parallel with the runway, as they line up with the wind and are practically invisible to the pilot.

(b) *Snowbanks* have also been used to mark runways. Snowbanks are doubly unsatisfactory because they are hard to see, and they are a hazard to aircraft that might run into them. Snowdrifts are not soft.

(c) The most satisfactory *wind indicator* for ice strips is a smoke barrel placed approximately one-half mile from the end of the runway.

(d) Where electrical power is available, runways should be marked for night operations with an airfield *beacon and cone-mounted strip lights.* The beacon should be a 500- to 1500-watt bipost, prefocus, 30- or 115-volt type, located on the highest structure in camp or on a hilltop within 2 miles of

the strip. The beam of the beacon should clear all obstructions. Strip lights should be placed along both sides of the runway, preferably at 200-foot intervals. Use 326 lumen, 6.6 ampere type. Where power is not available, use flare pots on top of the barrels marking the runway. In poor visibility, fuel can be burned in the barrels. The method of lighting should be explained to the pilots before they attempt an approach, so that they will have an idea of the size of the lights they see.

Figure 53. Photograph of lights on tops of barrels.

(e) Aircraft with radar can use *corner reflectors* placed at the end of the runway as approach aids. X-band radar reflectors at a Greenland Ice Cap site were picked up 50 miles out by an AN/APS 42. Figure 54 shows a corner radar reflector installed at Point Barrow, Alaska. Note that the support allows snow to blow through and thus prevents drifts from forming.

Figure 54. Photograph of corner radar reflector at Point Barrow, Alaska.

24. Aircraft Operations on Ice Surfaces

a. *Operational Criteria.* Successful aircraft operations on ice surfaces demand constant viligance and adherence to the ice-thickness criteria given in appendix 4. Criteria for regular operations give ice thicknesses that are safe for operations with minimum restrictions. The ice thicknesses listed for emergency operations involve some possibility of landing-gear breakthrough after the aircraft comes to rest, and should not be used unless that risk can be taken.

b. *Condition of Airfield During Operations*

(1) *Slush.* After an aircraft takes off during thawing temperatures, slush splashed against its control surfaces and into wheel wells may freeze and cause malfunctions. Normal operations should cease when heavy slush conditions are encountered. Slush is snow or firn saturated with water, and usually forms from melting snow during initial thaw. Slush may be visible from the air as grayish spots on a white surface, except when partly refrozen. In milder climates, with heavy snowfall, slush may form any time during the winter as well as during thaw. Slush may form when the weight of snow depresses the ice until water seeps up through cracks. Slush formations generally occur when snow cover approaches one-third the ice thickness. Slush forms frequently on rivers, from changes in water level. Dangerous double layers of ice form when slush freezes on top. Refrozen slush, or "snow ice," contains so many air bubbles it is only half as strong as clear ice.

(a) After thaw has set in, surface snow cover on ice runways will melt. This results in a *water-covered, bare ice* surface which gives very poor wheel traction. Windswept bare ice also gives poor wheel traction. *On thawing or wet ice, aircraft may be especially difficult to control during engine runup and will need wheel chocks with spikes to grip the ice.*

(b) *Bare sea ice* provides better trac-

tion than bare fresh ice does, and sometimes appears to have a sandpaper-like surface possibly resulting from downward drainage of surface brine. Traction on slick ice may be considerably improved by running a tractor over the surface to scar and corrugate it. This should be done less than 2 hours before landing; otherwise, ablation again smoothes the roughened surface. This process can be repeated as frequently as landings warrant.

(c) *Corn snow*—the coarse, granular, wet snow resembling finely chopped ice that sometimes forms on the ice surface during early thaw—improves braking action. Three inches or less of compacted snow on ice runways aids traction.

(2) *Whiteout.* Whiteouts, common to many parts of the arctic, may cause hazardous landing conditions. A whiteout is a weather phenomenon during which no shadows are visible, the horizon is indistinguishable, and only very dark objects are visible. A whiteout occurs when snow cover is complete and the sky is completely overcast with a thick cloud layer. This causes transmitted sunlight to be of about the same intensity as the light reflected by the snow. During a whiteout, and at other times of poor visibility, surface aids to orientation and depth perception are mandatory at ice strips. Proper airfield and runway marking, to include approaches, overruns, and runways, may satisfy the need for orientation and depth perception.

c. *Aircraft Operations:*

(1) *Landings—Normal.* During landings, the shock of impact is absorbed by the snow cover and the elastic resilience of the ice sheet. Breakthrough is most likely to occur during parking, if at all. No breakthroughs have yet occurred on ice runways that have been approved by competent ice survey teams.

(a) Aircraft should not make *wheeled landings* in snow deeper than one-third the wheel diameter. Deep, loose snow on runways hinders aircraft ground operations by causing excessive drag on landing gear and may seriously reduce visibility, especially at the point of propeller reversal.

(b) At ice-landing strips where there is no ground control, *cracks* on or near the runway should be marked by small flags in such a way that they are readily identifiable by pilots. Landings near wide-open cracks should be avoided.

(c) Under certain conditions, landings may be made on *floating ice* and the aircraft taxied with caution onto land or land-supported ice along the shore. Careful watch must be kept for cracks that may form between floating and landfast ice.

(2) *Landings—Emergency.* Emergency landings on smooth ice of marginal thickness are usually safer than emergency landings on land, or ditchings on water. Whether to make the emergency landing with wheels up or with wheels down will be the pilot's decision, based on his estimate of the ice thickness and on operating instructions currently in force for the particular aircraft involved.

(a) On *wheels-up landings,* the large contact surface distributes the aircraft's weight over a larger area than if the landing is made on wheels, and consequently there is less chance of breakthrough.

(b) On *wheels-down landings,* breakthrough at touchdown or during the landing roll is most unusual except on very thin ice. Breakthrough, if it occurs, may involve just a breakthrough of the landing gear and may leave the aircraft supported by wings and fuselage.

Landings on minimum ice thicknesses listed under *"Emergency"* in the table in appendix 4 are not recommended, except in real emergencies such as *rescue operations* or *forced landings.* The emergency tables provide insufficient safety factors against the aircraft breaking through the ice.

(3) *Taxiing.* Aircraft should taxi at right angles to cracks and avoid intersections of several large cracks. Parking or turning on cracks is not good practice. Aircraft should not approach an open crack or a free ice edge closer than a distance equal to at least one influence radius.

(4) *Parking.* Under marginal ice con-

ditions, ice failures are most likely to occur while an aircraft is parked—the result of prolonged load application . Noticeable sagging of the ice sheet precedes failure. During marginal ice conditions, the pilot should remain on the arcraft while the cargo is unloaded, and should keep the aircraft ready to move immediately if necessary. Two ground observers should measure ice deflection with an engineering level and rod; when they detect accelerated deflection, they should signal the pilot to move the aircraft immediately or to take off.

(a) If *deflection* of an ice sheet is gradual, the aircraft should be moved a distance at least equal to the influence radius when the deflection has reached 3 inches. If the ice fails, the landing gear will break through first and the belly and wings of the aircraft will rest on the ice for some time—in any event, long enough for the crew to scramble to safety. The second and third hours of parking are the most dangerous. Ice deflection may become two or three times larger than that reached during the first hour. After 3 hours, the ice may reach equilibrium with no further deflection taking place for the next 9 or 10 hours. Excessive deflection may be avoided by establishing the parking apron on shore, by reinforcing the parking apron by flooding, and by unloading the aircraft as fast as possible and taking off. The use of two or more parking aprons alternately gives the ice a chance to rest, regain strength, and heal repaired cracks.

(b) *Recommended spacing* between parked aircraft is computed from the influence radius of the minimum thickness of ice needed to support the aircraft. Close parking is advisable only on very thick ice. Two aircraft parked close to each other require one-third more thickness of ice than that required to sustain the weight of the heavier aircraft. Under conditions of minimum thickness, loads should be separated by at least 0.8 of one influence radius.

(c) Large, *presistent cracks* on parking aprons are dangerous and should be healed as soon as possible. If active cracks persist, parking aprons should be relocated or operations halted.

(d) Strict *operational discipline* should be maintained on ice runways at all times. Often extraneous personnel, vehicles, and equipment crowd around newly arrived aircraft, thus imposing unnecessary additional loads on the ice. Controls should be set up to prevent this practice. Ice should be thick enough to support all around handling equipment in addition to the aircraft.

(e) Ski-landing gear may sometimes freeze to the ice surface. *Freezedown* is easily prevented by retracting the skis during ground operations where possible, or by parking on pierced steel planking or boards.

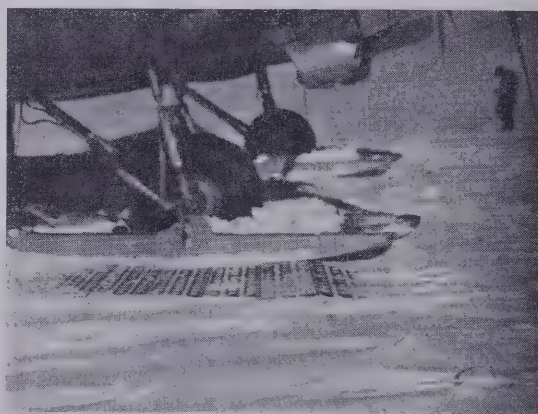


Figure 55. Photograph of ski-wheel aircraft parked on pierced steel planking.

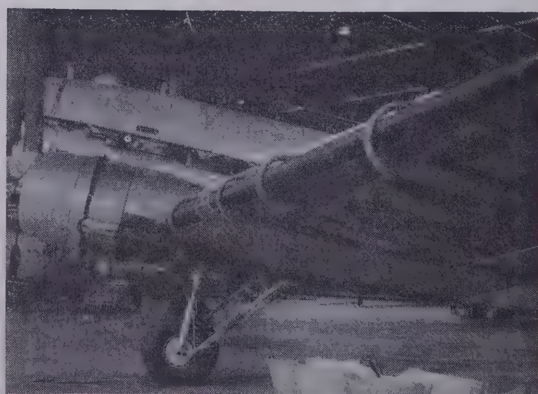


Figure 56. Photograph of leading-edge spoilers.

(f) During high winds, aircraft may have to be tied down—to heavy equipment such as tractors, or to *deadmen* buried in the ice. Wooden leading-edge spoilers were used successfully by the Northeast Air Command, in lieu of tiedown in high winds.

Appendix I

GLOSSARY OF SNOW AND ICE TERMS

Ablation:	The process of removing snow or ice from a glacier or snowfield by melting and evaporation.
Arctic Pack:	The drifting ice floes of the Arctic Ocean.
Barchan Drifts:	Crescent-shaped mounds of windblown snow; the arms of the crescent point downwind.
Candle Ice:	Disintegrating sea ice or fresh water ice consisting of ice prisms or cylinders formed perpendicular to the original ice surface.
Corn Snow:	Coarse, granular, wet snow resembling finely chopped ice that sometimes forms on an ice surface during early thaw.
Cryologist:	An ice scientist.
Deadman:	A log, stone, or other bulky object buried in the ground or frozen in ice, to which a guy line may be secured.
Degree-Days of Frost:	A measurement in temperature units computed as the difference between the average daily temperature and 32°F; the measurement is negative when the average daily temperature is below 32°F and positive when above.
DEW Line:	Distant Early Warning line, the line of radar stations crossing North America at approximately 70° North Latitude.
Fast Ice:	All types of sea ice, broken or unbroken, attached to the shore, beached, stranded, or attached to the bottom in shoal water.
Firn:	Old snow which has lasted through at least one summer; the flakes have changed to grains of spherical shape which may or may not be bonded together.
Firn Limit:	The lower occurrences of firn on a glacier. The lowest position of the permanent snow cover of an ice cap.
Floe:	A fragment of sea ice of any size, as distinct from an iceberg or other form of land ice; also the associated fragments or pack of such ice.
Frozen Lead:	Lane of water between floes which has frozen over.
Glacial Ice:	Land ice that is flowing or that shows evidence of having flowed.

Glacier:	A mass of snow, firn, and ice which is flowing or has flowed.
Hummock:	A mound or hillock in pressure ice.
Ice Cap:	Any ice sheet covering a large portion of a land area.
Ice Crust:	1. Thin, hard sea ice. 2. An ice band.
Ice Island:	Large, tabular mass of ice in the Arctic Ocean or adjacent waters several square miles in area and a hundred or more feet thick.
Ice Shelf:	A thick ice formation attached to land with a comparatively level surface extending seaward.
Lake Ice:	Fresh water ice formed on lakes.
Land Ice:	Any ice formed on land, even though it may be floating in the sea.
Landfast Ice:	Fast ice.
Melt Water:	Water resulting from the melting of snow or ice.
Old Floe:	Floe composed of ice two or more winters old.
Pack Ice:	Any large accumulation of floating ice driven closely together.
Polar Ice:	Sea ice two or more winters old.
Pressure Ridge:	A long ridge in sea ice caused by horizontal pressure.
Rafted Ice:	A form of pressure ice resulting from the overriding of ice cakes, pans, or floes on one another.
River Ice:	Any ice formed in or carried by rivers.
Sastrugi:	The Russian term for wind-deposited or wind-eroded irregularities, often sharp edged, on a generally featureless snow surface.
Sea Ice:	Ice formed by the freezing of sea water.
Slush:	Snow or firn saturated with water.
Snow Ice:	1. Frozen slush. 2. Ice crust on a water surface containing a large portion of fallen or drifted snow.
Whiteout:	A weather phenomenon during which no shadows are visible, the horizon becomes indistinguishable, and only very dark objects can be seen.
Winter Ice:	Ice less than a year old.
Young Ice:	Newly formed ice, 2 to 8 inches thick, in the transitional stage of development from ice crust to winter ice.

Appendix 2

GUIDE TO BASIC SOURCES OF INFORMATION

The basic source for all environmental information on a particular area is the National Intelligence Survey volume covering that area. The publications listed below supplement the NIS but do not replace it. ADTIC publication A–105, "Glossary of Arctic and Subarctic Terms," gives much background material as well as defines meanings and explains usages of terms employed in arctic literature. The Hydrographic Office "Sailing Directions" and the Coast and Geodetic Survey "Coast Pilots" give a great deal of data on climate, topography, and ice conditions in addition to purely hydrographic information. The titles of the other publications explain their purposes. Unless otherwise specified, the documents listed in this appendix may be obtained from the Government Printing Office, Washington 25, D. C.

U. S. AIR FORCE

1. AF Manual 200–30, Regional Photo Interpretation Series: "Antarctica" (Department of the Air Force, Washington, D. C. March 1953).
2. "Glossary of Arctic and Subarctic Terms" (obtainable from Air University, Maxwell Air Force Base, Alabama: Arctic, Desert, Tropic Information Center, Research Studies Institute, Pub. No. A–105, September 1955. 90 p.).

U. S. NAVY

3. "A Functional Glossary of Ice Terminology" (Washington, D. C.: Hydrographic Office, Pub. No. 609, 1952, 30 p., 110 photos).
4. "Aerial Ice Reconnaissance," 2d edition, Washington, D. C.: Hydrographic Office, Pub. No. H. O. Misc. 15603, 1956, 12 p.
5. "Sailing Directions for the East Coast of Greenland From Prince Christian Sound to Cape Morris Jesup and Iceland, Including the Island of Jan Mayen" (Washington, D. C.: Hydrographic Office, Pub. No. 75, latest ed. and supplements to date, illus., tables, maps).
6. "Sailing Directions for Baffin Bay and Davis Strait, Comprising the West Coast of Greenland From the Eastern Entrance of Prince Christian Sound to Cape Morris Jesup and the Coasts of Baffin,

Bylot, Devon and Ellesmere Islands From Resolution Island to Cape Joseph Henry" (Washington, D. C.: Hydrographic Office, Pub. No. 76, latest ed. and supplements to date, plates and maps).

7. "Sailing Directions for Northern Canada Including the Coast of Labrador North of St. Lewis Sound, the Northern Coast of the Canadian Mainland, and the Canadian Archipelago" (Washington, D. C.: Hydrographic Office, Pub. No. 77, latest ed. and supplements to date. fold. chart).

8. "Sailing Directions for the East Coast of Siberia, From Mys Otto Shmidta to Sakhalinskiy Zaliv (Sakhalin Gulf), Including Ostrov Vrangelya (Wrangel Island), Ostrov Gerald (Herald Island), Diomede Islands, Komandorskiye Ostrova (Komandorski Islands) and the Eastern, Northern, and Northwestern Coasts of the Okhotsk Sea" (Washington, D. C.: Hydrographic Office, Pub. No. 122A, latest ed. and supplements to date, illus., tables, sketch maps).

9. Sailing Directions for the Northwest and North Coasts of Norway From Feje Fjord to the North Cape and Thence to Jakobselva, Including Spitsbergen (Svalbard) and Jan Mayen Island" (Washington, D. C.: Hydrographic Office, Pub. No. 136, latest ed. and supplements to date, plates, tables, charts).

10. "Sailing Directions for the Northern U. S. S. R. Volume I, Mys Nemetskiy to Mys Kanin Nos" (Washington, D. C.: Hydrographic Office, Pub. No. 137A, latest ed. and supplements to date, illus., charts, tables).

11. "Sailing Directions for the Northern U. S. S. R. Volume II ,Mys Kanin Nos to Ostrov Dikson" (Washington, D. C.: Hydrographic Office, Pub. No. 137B, latest ed. and supplements to date, illus., charts, tables).

12. "Sailing Directions for the Northern U. S. S. R. Volume III, Ostrov Dikson to Mys Shmidta" (Washington, D. C.: Hydrographic Office, Pub. No. 137C, latest ed. and supplements to date, illus., charts, tables).

13. "Sailing Directions for Antarctica" (Washington, D. C.: Hydrographic Office, Pub. No. 138, latest ed. and supplements to date, plates and maps).

14. "Ice Atlas of the Northern Hemisphere" (Washington, D. C.: Hydrographic Office, Pub. No. 550, latest ed. and supplements to date).

15. Lee, Owen S. and Lloyd S. Simpson, "A Practical Method of Predicting Sea Ice Formation and Growth" (Washington, D. C.: Hydrographic Office, Technical Report No. 4, September 1954, 9 p., 4 charts, 13 tables).

U. S. ARMY

16. Assur, Andrew, "Airfields on Floating Ice Sheets for Regular and Emergency Operations" (Wilmette, Illinois: U. S. Army Snow Ice and Permafrost Research Establishment, Corps of Engineers, Report 36, latest ed. and supplements to date, tables).

17. "Depth of Snow Cover in the Northern Hemisphere" (Boston, Massachusetts: Artic Construction and Frost Effects Laboratory, New England Division, Investigation of Construction and Maintenance of Airdromes on Ice, Fiscal Year 1954, 1954, 4 p., 1 14–p, table, 38 plates).

U. S. COAST AND GEODETIC SURVEY

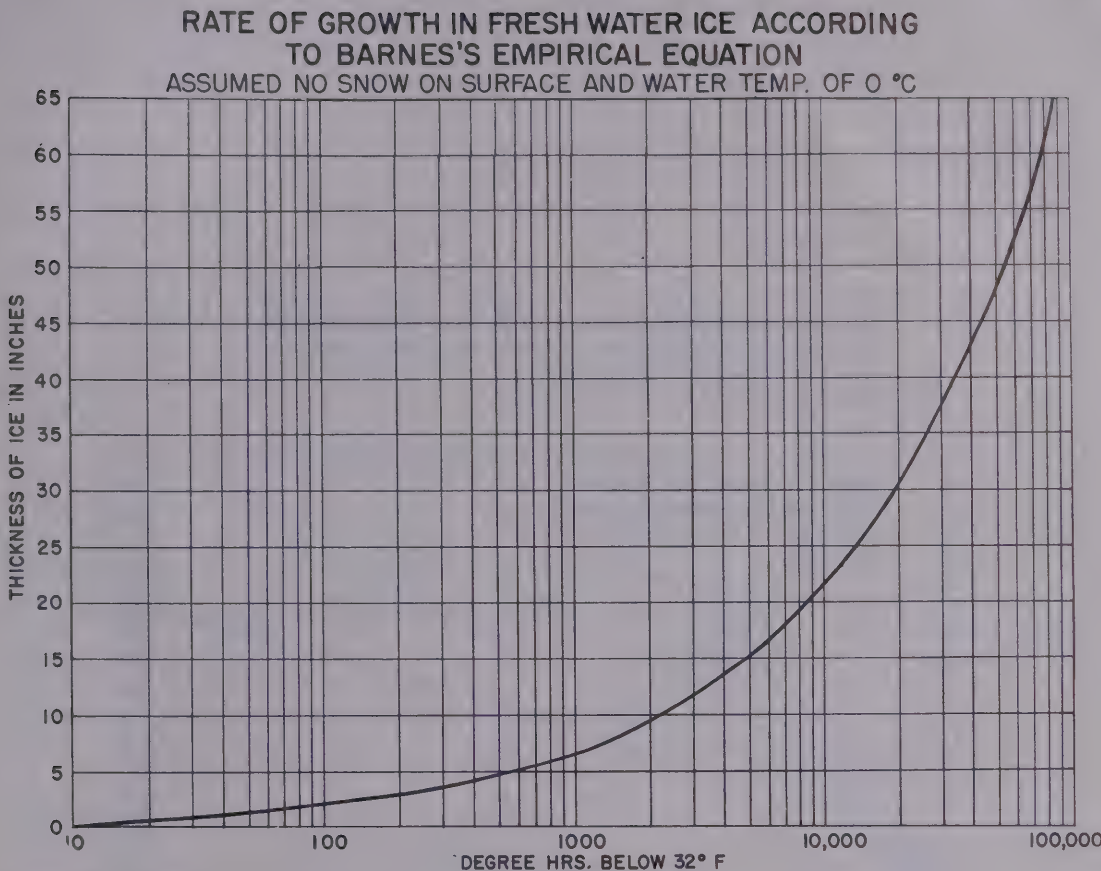
18. "United States Coast Pilot. Alaska Part II. Yakutat Bay to Arctic Ocean" (Washington, D. C.: Department of Commerce, U. S. Coast and Geodetic Survey, Serial No. 680, latest ed. and supplements to date, illus., plates, charts).

CANADA

19. Thomas, Morley K., "Climatological Atlas of Canada" (obtainable from the Department of Defense (DOD), Ottawa, Canada: Meteorological Div., Dept. of Transport, N. R. C. No. 3151, and Div. of Building Research, National Research Council, D. B. R. No. 41, December 1953, 255 p).

Appendix 3

ICE TABLES AND CURVES



Appendix 3, Graph I

Growth of Fresh Water Ice

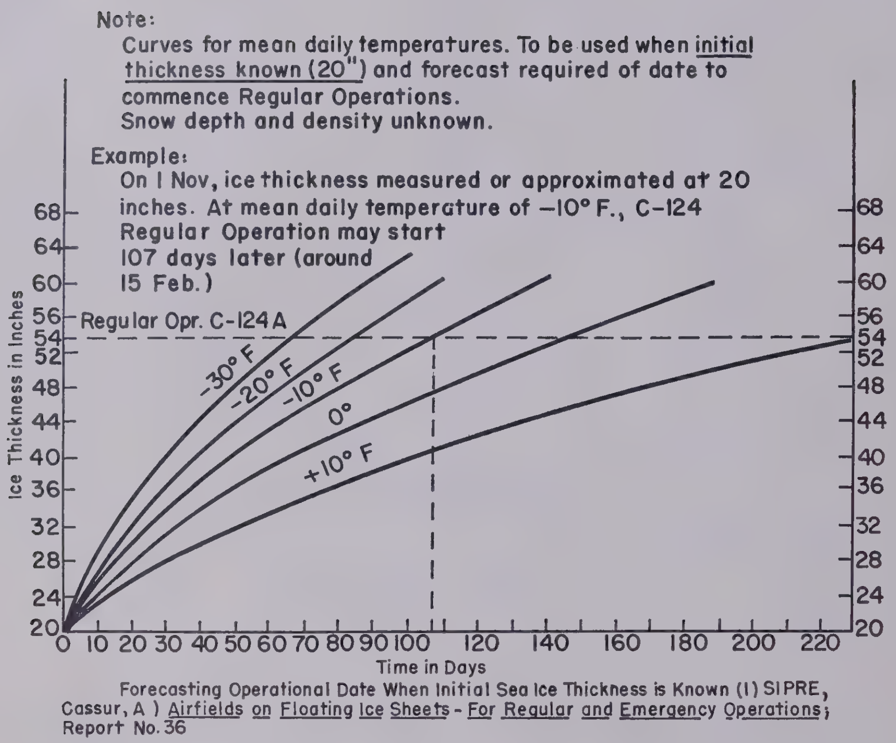
This graph is based upon the following empirical equation derived by Barnes from an analysis of observed data:

$$t = \frac{L\,S\,E}{K\theta}\left(1 + \frac{E}{2}\right)$$

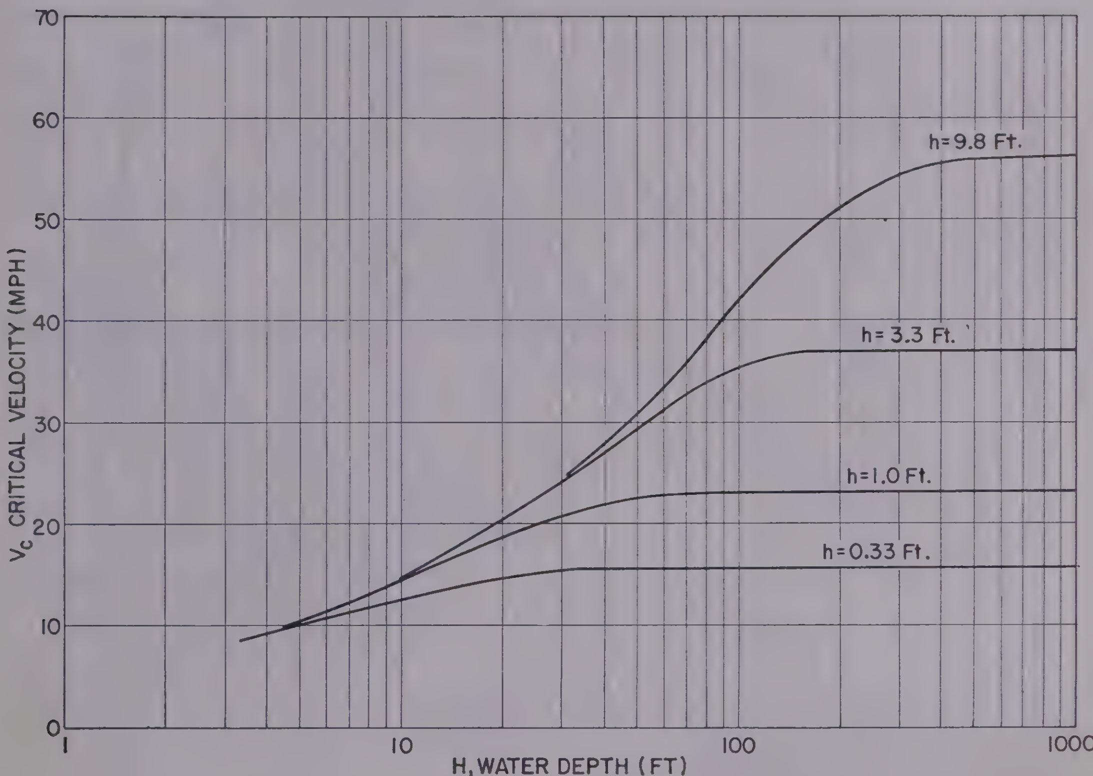
where t=time in seconds for ice sheet to attain a thickness E in centimeters
L=heat of fusion, 80 cal/g
S=density, 0.917 g/cm^3
K=thermal conductivity of ice, 0.0057 cal/cm sec °C
θ=difference in temperature between the underside of the ice sheet and the air temperature, in degrees centigrade. Since the underside of the ice sheet is normally in contact with water it may be assumed to be at 0°C and therefore θ=air temperature, changing negative sign to positive.

In the preparation of this graph, temperature has been expressed in Fahrenheit degrees and ice thickness in inches since most meteorological observations are reported in British rather than metric units.

Degree-hours below freezing are obtained by multiplying the difference between 32°F and the air temperpature by the number of hours during which the air temperature prevailed. For example, an air temperature of 27°F for 5 hours is (32—27)×5 or 25 degree-hours below freezing.

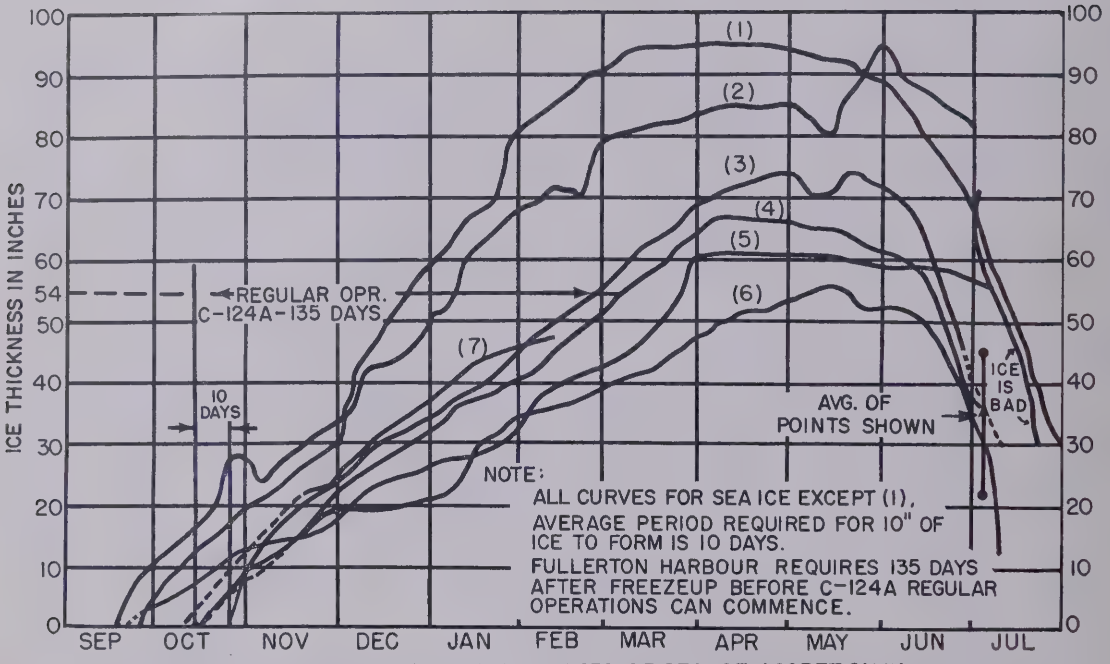


Forecasting Operational Date When Initial Sea Ice Thickness is Known (1) SIPRE (ASSUR,A) Airfields on Floating Ice Sheets—for Regular and Emergency Operations, Report No. 36, p. 18.



Critical velocity as a function of water depth, H, and ice thickness, h.

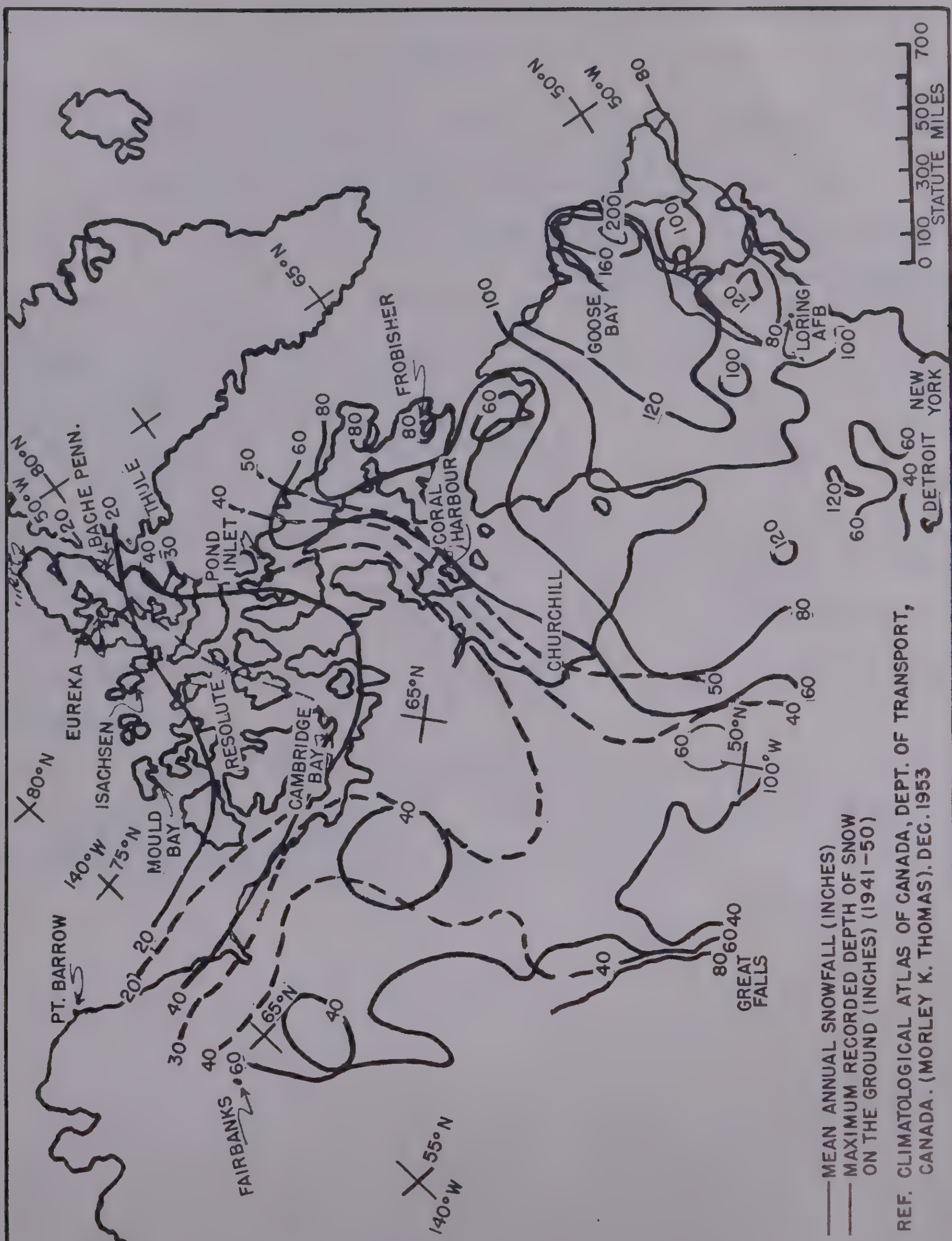
Appendix 3, Graph 3



OBSERVED NATURAL RATES OF SEA ICE ACCRETION (1).

CURVE (1) — RIVER CLYDE, BAFFIN ISLAND, FRESH ICE, (70° N).
(2) — WINTER HARBOR, MELVILLE ISLAND (67° N).
(3) — FULLERTON HARBOUR, HUDSON BAY (64° N).
(4) — FULLERTON HARBOUR, HUDSON BAY (64° N).
(5) — ALBERT HARBOUR, POND INLET, BAFFIN ISLAND (73° N).
(6) — ARCTIC BAY, BAFFIN ISLAND (73° N)
(7) — THULE, GREENLAND (76° N).

(1) ACFEL, REPORT OF INVESTIGATIONS, CONSTRUCTION AND MAINTENANCE OF AIRDROMES ON ICE, 1946-1948. CORPS OF ENGINEERS, U.S. ARMY, MAY 1948. PLATE NO. 5.



Appendix 3, Map 1

RECORD OF AIRCRAFT LANDING ON ICE

INSTRUCTIONS: ONE OF THESE FORMS WILL BE COMPLETED FOR EACH AIRCRAFT LANDING ON FLOATING ICE.

(1) LANDING SITE
NAME: ______________
LOCATION: ____________

(2) DATE OF LANDING
________19___

(3) OUTSIDE TEMPERATURE AT TIME OF LANDING
(IN DEGR. FAHR.) ______

(4) AIRCRAFT
MAKE: __________
MODEL: __________

(5) LANDING MADE ON
(Check one only)
☐ WHEELS ☐ SKIS

(6) GROSS LANDING WEIGHT OF AIRCRAFT PLUS LOAD
(in pounds) ________

(7) TYPE OF ICE
(Check one only)
☐ RIVER ☐ FRESH
☐ LAKE ☐ SALT
☐ SEA

(8) THICKNESS OF ICE AT LANDING SITE
(In inches) ________

(9) ICE THICKNESS SHOWN ON ITEM 8 WAS... (Check one only)
☐ MEASURED
☐ ESTIMATED

(10) THICKNESS OF SNOW COVER AT LANDING SITE
(In inches) ______________

(11) AIRCRAFT WAS PARKED FOR A PERIOD OF:
____DAYS____HRS____MIN.

(12) INDICATE WHETHER ADDITIONAL ICE CRACKING WAS NOTED BY EITHER AIRCRAFT OR GROUND CREW

	OBSERVED YES	OBSERVED NO	HEARD YES	HEARD NO
DURING TOUCHDOWN	☐	☐	☐	☐
DURING TAXI	☐	☐	☐	☐
DURING PARKING	☐	☐	☐	☐

REMARKS: INCLUDE COMMENT ON RELATIONSHIP OF ICE AND SNOW CONDITIONS TO ANY ACCIDENT INCURRED
(Use back of card if necessary)

Appendix 3, Table 1 (Sample Format)

Appendix 4

MINIMUM THICKNESS TABLE FOR LANDING AND PARKING AIRCRAFT ON FRESH-WATER ICE AND SEA ICE*

Explanatory Notes for Table

C–47 Aircraft

C–54 Aircraft

C–119 Aircraft

C–123 Aircraft

C–124 Aircraft

SA–16 Aircraft

*Data taken from SIPRE Report 36 and its supplement.

NOTES CONCERNING TABLE FOR LANDING AND PARKING OF AIRCRAFT ON FRESH-WATER ICE AND SEA ICE

1. For fresh-water ice, count only one-half the snow-ice thickness in the effective thickness. Snow ice (frozen slush) can be distinguished from transparent, black fresh-water ice by its white color. If the date of the snow-ice freezing is unknown, use one-half of the thickness of the snow ice.

a. For salt-water ice, count only one-third of the snow-ice (frozen slush) in the effective ice thickness during the first week after freezing, one-half during the second week, and two-thirds after three weeks. On salt-water ice, snow ice can be distinguished from hard ice by the inclosed round air bubbles; do not confuse air bubbles with the small pockets (irregular margins) that can be seen in strong sea ice.

2. With minimum ice thickness, three landings a day can be made using alternate parking places. If the ice thickness exceeds the minimum by 5%, eight landings a day can be made. The frequency of landings is not restricted, if the necessary ice thickness is exceeded by 10%.

3. Ice thicknesses given for emergency landings involve some risk of breakthrough of landing gear; the aircraft will not sink. If possible, remove the aircraft from the ice; if not, move the aircraft around on the ice.

4. If the gross weight is higher than that listed, add 6% to the ice thickness for a 10% weight increase; if the gross weight is less than that listed, deduct 5% of the ice thickness for 10% less weight.

5. The value of "air temperature" used is the average temperature for the following number of days:

Inches of ice:	*Below 20*	*20 to 40*	*Above 40*
Number of days:	3	4	5

For temperatures higher than those given, increase the required thickness by up to 20% more at 40°F; suspend operations if the maximum temperature exceeds 40°F.

6. Increase the required ice thicknesses by one-tenth for dry cracks (cracks without water) up to 1½ inches in width; increase by one-third for wet cracks (cracks with water in them) up to 2½ inches in width. *Aircraft must cross cracks at right angles.*

7. Parking up to 1 hour under regular operations; increase required thickness by 25% for 24-hour parking, and move aircraft daily under low-temperature conditions (below 10°F for sea ice, or 14°F for fresh-water ice). Under medium temperature (19°F or 22°F), only 6-hour parking is allowed with 25% more thickness than required by the table. Under higher temperature (28°F or 31°F), parking beyond 1 hour is not recommended unless the ice thickness substantially exceeds requirements. At these higher temperatures, the deflection of the ice under the load should be measured at frequent intervals with a rod and transit; the aircraft should be moved immediately if accelerated deflection is observed.

8. Occasional cracking should not cause concern; use two parking places alternately—if cracking is frequent, use two airstrips alternately. Suspend operations, if noticeable sagging is observed.

LANDING AND PARKING OF AIRCRAFT ON FRESH-WATER ICE AND SEA ICE

(Data as of April 1956)

(Number in Parentheses Refer to Notes on Facing Page.)

Type	Gear (7) Wheel	Gear (7) Skis	Assumed Gross Weight (Thous. lbs) (4)	Fresh-Water Ice: Regular (2) 14°	22°	31°	Fresh-Water Ice: Emergency (3) 14°	22°	31°	Sea Ice: Regular (2) 10°	19°	28°	Sea Ice: Emergency (3) 10°	19°	28°
				Parking Intervals (Feet) (7) per Ice Thickness (Inches) (1) (6) at Air Temperatures Shown (°F) (5) (6) — Operations											
C–47/D	X		29.0	17½″	19½″	22″	12½″	13½″	16″	26″	30″	35″	19½″	22″	26″
				110′	120′	130′				130′	140′	160′			
		X	30.5	15½″	17″	19½″	11″	12″	14″	23″	27″	32″	17½″	20″	24″
				100′	110′	120′				120′	140′	150′			
C–54/G	X		67.5	25″	28″	32″	17½″	19½″	22″	36″	41″	49″	26″	30″	36″
				140′	160′	180′				180′	190′	220′			
C–119/B	X		61.8	22″	25″	28″	16″	17½″	21″	34″	37″	45″	25″	28″	34″
				130′	140′	160′				170′	180′	200′			
C–123	X		46.5	22″	25″	29″	16″	18″	21″	33″	37″	44″	24″	28″	33″
				130′	140′	160′				160′	180′	200′			
C–124/A	X		168.0	40″	45″	51″	28″	32″	36″	54″	62″	74″	40″	46″	54″
				200′	220′	250′				230′	260′	290′			
C–124/B	X		202.0	44″	49″	57″	32″	36″	41″	60″	68″	81″	44″	50″	59″
				220′	240′	260′				250′	270′	300′			
SA–16	X		31.4	16½″	18½″	21″	13″	14½″	16½″	28″	32″	38″	21″	24″	29″
				100′	110′	130′				140′	150′	170′			
		X	31.4	18½″	21″	24″	13½″	15″	17″	28″	32″	38″	21″	24″	29″
				110′	130′	140′				140′	150′	170′			

Parking interval is for ice of minimum thickness. On ice 1/3 thicker than minimum, two aircraft can be parked side by side. In parking aircraft of different types, the parking interval for the heavier aircraft should be used.

Appendix 4, Table I

Appendix 5

CRITERIA FOR USING SELECTED HEAVY EQUIPMENT ON SEA ICE

Remarks Concerning Tables of Ice Thicknesses for Traffic Over Sea Ice

1. The recommended ice thicknesses are not in a simple relation to the gross weight, since configuration of the loading surface is considered.

2. Gross weight is given on the basis of available information. If the gross weight is slightly higher by "c" percent, the required ice thickness has to be increased by "bc" percent; the factor "b" is given in column three. Rule of thumb: add 5–6 percent ice thickness for a 10 percent increase in weight. The ice thickness may be reduced in the same proportion if the gross weight is less.

3. It is to be understood that, in a given area, the minimum ice thickness will govern the loading criteria for safety. This is especially important at the place of parking. The ice thicknesses can easily be checked with a SIPRE ice-thickness kit or equivalent.

4. The recommended distance between parked or moving vehicles is given in Table 2. In order to apply the criteria for "far from edge," the vehicle should be located at least at the "distance from edge" specified in Table 2. *Example:* Ice thickness 38 inches, average air temperature below 10°F. How far should a Caterpillar Traxcavator stay from the edge in order to apply criteria for the case "far from edge"? Answer: The necessary ice thickness for regular operation according to Table 1 would be 24 inches. Table 2 gives for this thickness a distance of approximately 115 feet. Under emergency conditions, the required ice thickness would be 18 inches, and the distance about 95 feet. No great significance should be attached to keeping these distances exact.

5. Figures given for emergency operation involve some risk of breakthrough. Vehicles in this case should be operated by means of ropes attached to the steering mechanism. Men will be safe beyond the distance specified in Table 2, last column. Direct danger exists only very close to the vehicle. Fast crossing over refrozen leads with ice thicknesses specified under emergency operation will help to avoid losses.

6. Operations on the edge might be necessary during unloading from ships or for crossing over leads by means of temporary bridges. For short periods, the criteria given under the column "on edge" can be used when necessary. Parking on the edge is not recommended. The best procedure is to unload equipment, from the ship, on sleds located on the ice and tow these sleds by tractors located at the distance specified in Table 2. Heavier stationary loads should be kept away from the edge and from other loads.

If bridges are used, the supports must cover a reasonable maximum of area. For each end-support, this area should be a minimum equal to the equivalent of the area covered by the vehicle. The members of the bridge must be sufficiently rigid to avoid excessive bending, which might result in a severe concentration of loading on the ice edge. Use at least two bridges and alternate for operational purposes.

7. Air temperature is the average over the following number of days:

Ice thickness (inches):	*Below 20*	*20 to 40*	*Above 40*
Number of days:	3	4	5

8. If operations have to proceed under average air temperatures higher than 28°F, the required ice thicknesses given in these columns must be gradually increased by up to 20 percent. Suspend operations if maximum air temperature exceeds 45°F.

9. Parking up to ¾ hour under regular operation. Increase required thickness up to 25 percent for 24-hour parking and move vehicle daily under low temperature conditions (below 10°F). Under medium temperature (19°F), only 6-hour parking is allowed, with 25 percent more thickness than required by Table 1. Consider remarks 2, 8, and 10. Under higher temperature (28°F, parking beyond 1 hour is not recommended, unless the ice thickness substantially exceeds requirements. Vehicles should be parked on alternate location in order to allow the ice to recover.

10. Increase required ice thickness by 10 percent for dry cracks (width up to 1½ inches) and by 1/3 for wet active cracks (width up to 2½ inches). Disregard hair cracks. Cross active cracks at right angles.

11. On ice fields that are subject to considerable lateral pressure and hummocking (pack ice), the required ice thicknesses should be increased by 10 percent.

12. A fairly light snow coyer up to 6 inches is assumed. Greater ice thickness is recommended when the ice is covered by deep snow or when used less than 2 days after removal of deep snow.

13. Sometimes a deep snow cover is penetrated by sea water. Travel over slush-covered ice, if necessary, must proceed according to the criteria specified under the column for 28°F, disregarding the actual air temperature. Continue application of these criteria for 3 days for ice thicknesses up to 30 inches and for 5 days if the ice is thicker than 40 inches. Then increase the required ice thickness by 20 percent and continue for an additional 3 days. Suspend operations thereafter.

14. The slush period can be cut down by flooding, which can be accelerated by drilling holes in the ice as soon as slush becomes evident in the lower snow layers. If the slush layer completely freezes, count only 1/3 of the frozen slush layer in the effective ice thickness during the first week after freezing, ½ during the second week, and 2/3 after two weeks.

Example: A 20-inch sea-ice sheet is covered by a 14-inch snow cover, which depresses the ice to such an extent that the water penetrates the ice surface and saturates the snow. Under this condition, none of the vehicles listed in Table 1 should be allowed on the ice even under emergency conditions. If the slush layer freezes to a 9-inch "snow ice" layer, the effective ice thickness is $20+9/3=23$ inches during the first week, 24½ inches during the

second week, and 26 inches thereafter. Provided the average air temperature is below 10°F, all vehicles can be used even for regular operation, with the exception of the 71,000-pound D-8, which is allowed to pass only under emergency conditions, applying the precaution under point 5.

15. Occasional cracking should not lead to concern. Use alternate roads. Suspend operation if noticeable sagging is observed. Do not pass over or on cracked edges.

Table 1. SIPRE Table for Emergency and Safe Traffic Over Sea Ice (Issued October 1956—Selected Vehicles)

(Numbers in Parentheses Refer to Remarks)

Vehicle	Gross Weight (Thous. lbs.) (1,2)	"Factor" b (2)	Sea Ice Thickness, Inches (2, 3, 8-11, 13, 14)											
			Emergency Operation (5)						Regular Operation					
			Far From Edge (4)			On Edge (6)			Far From Edge (4)			On Edge (6)		
			Air Temperature, °F (7)						Air Temperature, °F (7)					
			10°	19°	28°	10°	19°	28°	10°	19°	28°	10°	19°	28°
Pettibone "Cary Lift" empty, fork retracted	1785	0.57	16	18	23	28	33	41	20	23	29	36	41	51
Same, 6,000 lb. load; fork extended	2385	0.50	18½	20	27	34	40	49	24	28	34	41	47	62
Same, 10,000 lb load; fork retracted	2785	0.50	19½	21	28	37	43	54	25	29	36	46	52	66
Caterpillar Traxcavator, LGP 955	2610	0.53	18	21	26	33	38	48	24	27	35	41	47	61
Caterpiller-Bulldozer LGP D-8 (Special Construction)	7085	0.55	26	31	40	51	59	77	36	42	53	65	77	99

NOTE: Do not use or reproduce this table without the remarks on the preceding pages.

Table 2. Recommended Safe Distances on Sea Ice

(Numbers Refer to Remarks)

Ice Thickness (1)	Distances Between Vehicles or Loads, Feet			Distance From Edge (Feet) (3)	Distance of Personnel From Vehicle, While Operating Under Emergency Conditions (Feet). (4)
	Parked	Moving			
		Two	Several in Formation (2)		
15	130	60	100	85	13
20	160	75	130	100	17
30	220	100	170	140	25
40	280	130	220	170	32
60	370	180	290	240	45
80	470	220	360	290	58
100	550	260	430	350	70

Notes: Consider the distances in this table as guides. Some deviations are permissible, if the situation requires them.

Remarks:

1) Use the ice thicknesses required in Table 1 for the given vehicle, operation, and temperature conditions.

2) Slow-moving vehicles, as listed in Table 1, are assumed. Request special criteria for trucks moving at higher speeds, causing resonance waves.

3) Vehicles should be kept *at least* at this distance before criteria under "far from edge" (Table 1) are applied. If necessary, move vehicle closer and increasing the ice thicknesses up to the values given under "on edge" in Table 1.

4) This is the distance from the margin of the vehicle at which a circumferential crack is expected to form before failure occurs. The ice sheet, however, will support men closer, even up to a few feet from the vehicle. Do not hesitate to stay closer, *if necessary*, being aware of the possibility that the vehicle may tip over.